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VARIATIONS IN THE FRESHWATER SNAIL, GONIOBASIS LIVESCENS.

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INTRODUCTION.

In the course of some general ecological field work in the Bass Island region of Lake Erie, it was observed that the shells of the snail *Goniobasis livescens* varied considerably in shape and size. It occurred to me that it might be possible to correlate these variations with the degree of exposure to wave action. With this end in view, collections were made in this region during the summer of 1924, while in residence at The Lake Laboratory, Put-in-Bay, Ohio. By way of comparison some *Goniobasis* were collected in the Scioto and Olentangy rivers, near Columbus. The standard used as basis of comparison is the average obesity. My reason for choosing it and the definition of it are given in the section devoted to the description of the method.

On looking over the literature on the ecology of fresh-water mollusks, I have found several instances where variations within a species of mollusks are correlated with environmental factors. This evidence is based partly on actual experiments under control, partly on observations and measurements.

Colton ('08) has shown experimentally for Lymnaea columella Say, that the following factors may be the cause of dwarfing: large water plants (doubtful results), sediment, cold (indirectly through its effect upon the food supply and directly through its influence upon the physiological processes), improper aeration, volume of water, lack of exercise, and accumulation of excreted matter. He also found that in alternating favorable and unfavorable conditions, as, for instance, cold and warmth, and feeding and starving, the rate

of growth exceeded the rate of those which were always under favorable conditions. This was true even when in the case of alternating temperatures the latter was reduced to the freezing point.

The following is quoted from Colton, Variations In the Dog Whelk *Thais* (*Purpura Amt.*) *lapillus*: "An examination of a large series of Thais (Purpura), the purple sea snail or dog whelk, from one hundred and six stations seems to indicate that variation in size and shape of shells is the result of the direct effect of environment." Colton found that shells collected from an exposed coast had a relatively wide aperture; (ratio of the height to the width 1.32+.004) while in those shells collected in sheltered bays with plenty of food the aperture was relatively narrow, (ratio of height to width being 1.70 +.009). Then he goes on to say, "The greater area of the foot (aperture) of those exposed to the surf is a direct reaction to the environment in preventing the animal from being destroyed by the surf. Since there is no overlapping of these characters, it is evident that we are here dealing with the direct effect of the environment." Brot observed in a lake near Geneva, Switzerland, that, "If a snail be long dwarfed and later be put under favorable conditions, the shell is often strangely distorted. Baker ('18) found that *Goniobasis livescens* varied in obesity in Lower South Bay of Oneida Lake. Some that he found were unusually long and narrow.

Ball, ('22) reports that in some species of fresh-water mussels the obesity seems to be directly proportional to the amount of waterflow. Steuer reports some very interesting variations in several species of plankton that apparently are correlated with environmental factors, namely, temperature, salinity, density of water, depth. Some of these variations occur at different localities, while others appear as seasonal variations at the same locality. Most of these variations consist in an abnormal development or a corresponding reduction of some part of the body, and seem to be a mechanism that enables the organism to float in a medium that varies in density or in salinity at different seasons of the year.

Other instances of the effect of the environment will be mentioned under the discussion of factors that may limit the distribution of mollusca.

Goniobasis livescens is a fresh-water mollusk. It belongs to the sub-class Streptoneura of the class Gastropoda and to

the family Pleuroceridæ of the order Pectinobrachia. It is the only species of *Goniobasis* found in this region.

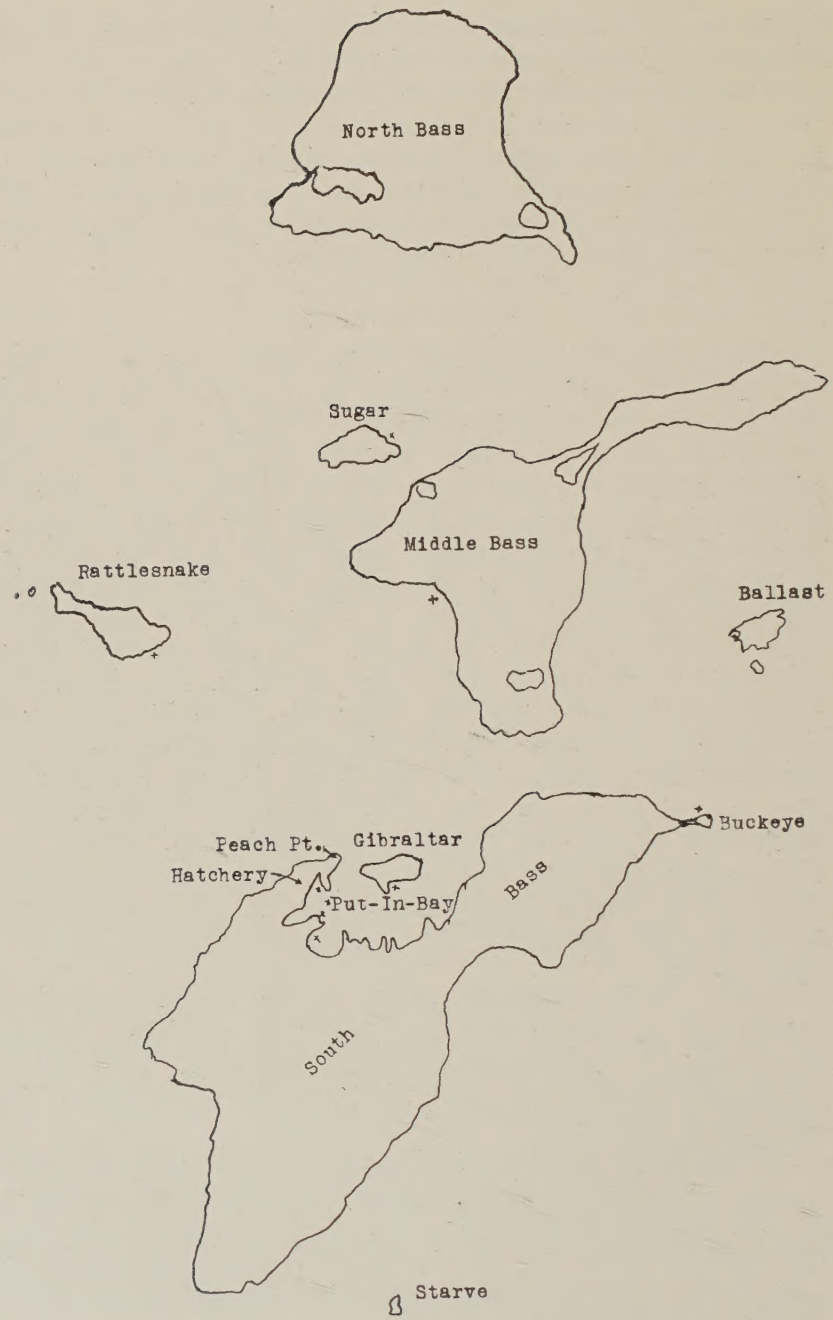
I want to take this opportunity to thank Dr. F. H. Krecker, under whose direction this work was done, for suggesting the problem and for helpful criticism as the work progressed. The identification of the snail was made by Mr. Bryant Walker in connection with some work done by Dr. Krecker. Mr. Walker's kindness is greatly appreciated.

Method.

The first step in the solution of the problem was the selection of a number of stations from which material could be collected. In the selection of stations special attention was paid to the degree of exposure to wave action. The first series of five stations is in the vicinity of the State Fish Hatchery, which is situated on the west shore of Hatchery Bay, a subdivision of Put-in-Bay. The first station, Peach Point, is at the entrance to Hatchery Bay; the second station is an old dock a short distance beyond the entrance to Hatchery Bay and almost in front of the State Fish Hatchery. The third station is along the shore of Hatchery Bay from the U. S. Fish Hatchery, which adjoins the State Fish Hatchery to Smith's Point at the entrance of Squaw Harbor, another subdivision of Put-in-Bay; the fourth station is the west shore of Squaw Harbor; the fifth station is on the Put-in-Bay side of Gibraltar Island, which lies across the entrance to Put-in-Bay. These five stations represent a definite series with respect to wave action. From Peach Point to Squaw Harbor there is a gradual decrease in the degree of exposure. At Gibraltar the degree of exposure increases again.

The remaining six stations are selected near the following islands and are named after them in the tables: Ballast, Middle Bass, Buckeye, Rattlesnake, Sugar, and Hen. All stations except the one on Hen Island, are indicated on the map of the Put-in-Bay region.

In the collection of snails special care was taken to secure mature individuals. In the young shells the spires are sharp, conical, and the whorls distinctly keeled. While the old shells have obtuse spires and the whorls are not carinated except in some of the very long individuals where the last 2 or 3 whorls may be carinated.



MAP OF THE BASS ISLAND REGION OF LAKE ERIE
Scale: 4 cm. = 1 mile. Stations are indicated by +.

One hundred of the largest specimens from each station were carefully measured to determine the length and the width. The distance from the apex to the lower edge of the lip was taken as the length, while the diameter just above the apex of the aperture was chosen as the width. This width is not quite the same as the greatest diameter, but it is more easily measured and for a comparative study it is just as good. All measurements were made to the tenth of a millimeter with a vernier caliper.

The unit chosen as a standard for comparison is the average obesity. It was chosen because it involves both the length and the width of the shells and is therefore a convenient standard of comparison. The average obesity is defined as the quotient of the average width by the average length. If O = ave. obesity, W = average width, and L = average length, we get the equation $O = W/L$.

From this formula it follows that the average obesity varies directly as the average width and inversely as the average length.

The average length is the sum of the lengths of one hundred shells divided by one hundred. Similarly the average width is the sum of the diameters of a hundred individuals divided by one hundred.

Finally the obesity of each shell separately was calculated to get the maximum obesity, the minimum obesity and the difference between these two.

Description of the Stations.

No. 1. This station is at the western edge to the entrance of Hatchery Bay. The most characteristic feature of this station is a bar extending into Hatchery Bay in a southeastern direction. The substratum on the northeast side of the bar consists in part of pebbles and small stones and in part of a smooth rock bottom. The shore on this side is subject to almost continual wave action from the open lake. It is exposed to waves coming in from the southwest and also to some coming from the northeast. The substratum on the southeast side of the bay consists of stones varying from a few cubic inches to several hundred cubic inches. This part of the shore is exposed to much less wave action because most of the waves break against the bar or on the shore below the bar. *Goniobasis livescens* were quite common in a few inches of water on the

protected side of the bar, while on the exposed side very few individuals were found and those in deeper water. The water over this area varied in depth from a few inches to a depth of four feet.

No. 2. This is a part of an old dock about 50 yards southeast of Station No. 1, just beyond the entrance to Hatchery Bay and almost in front of the State Fish Hatchery. The dock is built up of horizontal timbers and then filled up with stones of considerable size. In some places the stones are covered with a few inches of water, while in others they extend above the surface of the water. The water surrounding the dock is about 13 feet deep. This station is less exposed to wave action than Number 1, because much of the effect of the waves is lost when they hit the bar at Peach Point. On both the timbers and the stones *Goniobasis* were found in a few inches of water.

No. 3. The edge of Hatchery Bay from the U. S. Fish Hatchery, which adjoins the State Fish Hatchery, to Smith's Point, at the entrance to Squaw Harbor, another subdivision of Put-in-Bay. The water is uniformly shallow; in most places it is less than 3 feet in depth. The substratum is varied; in part it is composed of a smooth rock bottom, partly of smaller and larger stones, and partly of larger boulders. The shore for some distance consists of a cement wall. Wave action is relatively small, since only waves coming from the northwest could break on this shore and some of these are broken at Peach Point bar, at Gibraltar, and at docks just beyond the entrance to the bay. This makes the part of Put-in-Bay known as Hatchery Bay, a well protected situation. *Goniobasis* are common on the larger stones and boulders, and are plentiful on the cement wall. But everywhere they are in very shallow water, rarely exceeding a foot in depth.

No. 4. A subdivision of Put-in-Bay called Squaw Harbor. The water averages around 3 feet in depth and is very turbid. In many places the bottom is covered with mud or silt. Close to the western edge of the shore where the collecting was done, are many large stones barely covered with water. The bank consists in part of large stones piled up artificially and in part of a cement wall. Wave action of any degree is very rare as Gibraltar Island cuts off the waves coming in from the northwest, and South Bass cuts off all waves from the west, south, and practically all that come from the east. *Goniobasis* are

very plentiful on the stones along the bank as well as on the cement wall. I found a number of *Goniobasis* on one stone about 15 feet from the shore and in 3 feet of water.

No. 5, Gibraltar Island, situated at the entrance to Put-in-Bay. The north side of the island faces the open lake and all the waves that pass between Middle Bass and Rattlesnake break either at Peach Point or on the north side of Gibraltar. Consequently the north side is exposed to a great deal of wave action. The south side faces Put-in-Bay and has very little wave action. The station No. 5 is along the protected side of the island. It is not as well protected as Squaw Harbor, because some waves from the northeast may wash this shore. The substratum is composed of stones varying from a few cubic inches to several hundred cubic inches. The water varies in depth from a few inches to about 5 feet. *Goniobasis* are very abundant both on the stones and on the timbers of a small dock, but they always occur in a few inches of water.

No. 6, Ballast Island, northeast of the eastern end of South Bass and east of Middle Bass. The island as a whole is exposed to the full force of wave action from the open lake. But on the side facing Middle Bass there is a little cove protected from the northwest by an old dock and from the southeast by a bar. This protection is not sufficient to cut off all wave action. The station is freely exposed to waves from the southeast and also, though to a less extent, to those from the southwest. A look at the map will indicate that Ballast is more exposed than the south side of the bar at Peach Point. But because of this cove, Ballast is less exposed than Buckeye, which will be described next. The substratum is made up of larger stones. *Goniobasis* are abundant on the stones in a few inches of water.

No. 7. This station is located on the north side of Buckeye Island. The substratum is mostly a smooth rock bottom over which a few boulders have been strewn. The water is very shallow and gets deeper only very gradually. The island is just as much exposed to wave action as Ballast is; and the station here is more exposed than the one at Ballast, because there is neither bar nor dock to break the force of the waves. *Goniobasis* are rather rare and are found on the larger boulders only.

No. 8, Rattlesnake Island, about a mile northwest of Peach Point. The entire shore is well exposed to wave action from

the open lake. The station is a pile of rock and timber on the side facing Peach Point. This side is least exposed. This station is more exposed than Buckeye, but it has also a more favorable substratum. A few *Goniobasis* of an unusually small size were found on the larger stones and the timbers in a few inches of water.

No. 9. This station is on the western side of Middle Bass Island near a point where the shore makes a sharp turn towards the west. The station is so situated that the wave action is greatly reduced by this curve in the shore. Still the station is exposed freely to the waves from the northwest and from the west. Rattlesnake, which is due west of this station, helps to reduce the amount of exposure from the west. Hence this station is considerably less exposed than the one at Rattlesnake.

The station proper is an old dock built up of timbers and then filled in with stones. The end farthest out in the lake was only partly filled, so that the water covered the stones to a depth of from 12 to 20 inches. A few *Goniobasis* were found on the sides of the dock, but on the inside on stones as well as on the timbers they were quite plentiful in a few inches of water.

No. 10, Sugar Island, due west of Middle Bass. The station is along the northeastern shore of the island. While Sugar Island on the whole is less exposed to wave action than is Rattlesnake, the station proper is more exposed than the one at Rattlesnake. It gets the full force of waves from the open lake passing between Middle Bass and North Bass and also waves passing to the west of North Bass. It is therefore well exposed and gets the full force of both the east and northeast winds. The substratum is partly a smooth rock bottom and partly smaller and larger boulders. The water varies in depth from a few inches to about 3 feet. *Goniobasis* are rather rare and are found only on the larger stones and boulders and at a depth averaging about 18 inches.

No. 11, Hen Island, about 10 miles south of South Bass. It is out in the open lake and is exposed to the full force of wave action from all directions. There are no islands near enough to break the force of the waves as there are at Sugar Island. Hen has therefore, a higher degree of exposure than any other station in this series. The station proper is a dock built in the shape of a capital L. It extends for about 30 feet into the lake and then for about an equal distance it extends parallel with the shore. The average depth of the water surrounding

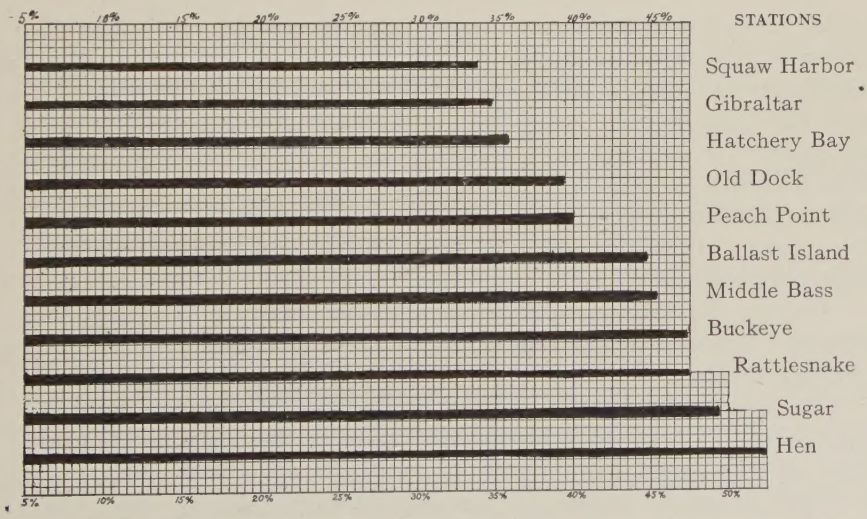
the dock is about 4 feet. A few *Goniobasis* were found on all sides of the dock and also on the larger stones between the dock and the shore. However, at the bend in the dock where the floor and the side of the dock had been partly torn up, and where large stones were submerged in shallow water, *Goniobasis* were quite plentiful. The description of the dock might create the impression that this station is after all fairly well protected. It must be remembered, however, that when the winds come from the right direction the dock and boulders are exposed freely to waves from the open lake. Again snails migrate into less protected areas during fair weather, then when it gets rough they seek a sheltered place.

In the description of the stations three factors have been emphasized, namely, substratum, depth of water, and degree of exposure to wave actions. It is readily apparent that these stations differ principally with respect to exposure to wave action.

Results.

Measurements and calculations made as suggested in the paragraphs on method, soon yielded some very definite results. These results are embodied in Tables I–IV. The average obesities are also represented graphically.

Graphic Representation of Obesities at



Percentages of Obesities represented by horizontal lines. One square = 5%.
(The first five percent are not shown.)

Table I shows the average obesity, mean obesity, minimum obesity, maximum obesity, and the difference between the last two. All are in terms of percent.

The first column of Table I is the most important, since the average obesity is the standard of comparison. It might be well to recall at this point that the stations in Tables I–III are arranged with reference to the degrees of exposure. From Peach Point to Squaw Harbor the degree of exposure is decreasing, while from Gibraltar to Hen Island it is again increasing. Squaw Harbor has the lowest degree of exposure.

TABLE I.

Station	Average Obesity	Mean Obesity	Maximum Obesity	Minimum Obesity	Difference
	Percent	Percent	Percent	Percent	Percent
Peach Point....	40.00	40.45	49.70	31.20	18.5
Old Dock.....	39.30	40.00	50.30	29.70	20.6
Hatchery Bay..	35.8	36.65	44.5	28.8	15.7
Squaw Harbor.	33.6	32.2	43.3	27.1	16.2
Gibraltar.....	34.1	38.45	48.1	28.8	19.3
Ballast.....	44.6	46.05	52.4	39.7	12.7
Middle Bass....	45.20	44.55	54.7	34.4	20.3
Buckeye.....	47.4	48.5	55.9	41.1	14.8
Rattlesnake....	47.5	49.05	58.2	38.9	19.3
Sugar Island...	49.3	48.25	55.6	40.9	14.7
Hen Island.....	52.44	56.2	67.3	45.1	22.2

On examining the figures of the first column of Table I, it is at once apparent, that (1) a very distinct difference in the average obesity exists, (the total variation amounting to 18.84%, and (2) that these variations in average obesity follow the variations in the degree of exposure to wave action, i. e., from Peach Point to Squaw Harbor the average obesity decreases and from Gibraltar to Hen Island it again increases. In short the average obesity seems to be directly proportional to the degree of exposure.

Column 2 shows the mean obesity and with the exception of Middle Bass and Sugar Island, it follows the same trend as the average obesity.

The maximum obesity varies in case of Sugar Island and Old Dock. The minimum obesity varies in the case of Middle Bass and Rattlesnake.

The greatest difference between the maximum and the minimum occurs at Hen Island and amounts to 22.2%. The least difference occurs at Ballast and amounts to 12.7%.

Table II gives the average lengths, mean lengths, maximum lengths, the minimum length, and the difference between the maximum and the minimum.

Column one shows that with a few exceptions the average lengths follow the same trend as did the average obesities, namely, the average length increases from Peach Point to Squaw Harbor, when it reaches the maximum, then at Gibraltar it begins to decrease until a minimum is reached at Rattlesnake. For Sugar and Hen Islands the average length is again slightly greater.

Table II.

Station	Average Length in mm.	Mean Length in mm.	Minimum Length in mm.	Maximum Length in mm.	Difference
Peach Point....	17.86	18.1	14.5	21.7	7.2
Old Dock.....	18.12	19.85	15.0	24.9	9.9
Hatchery.....	19.76	20.4	16.4	26.4	10.0
Squaw Harbor.	20.86	21.2	16.4	26.0	9.6
Gibraltar.....	20.25	21.9	16.8	27.0	10.2
Ballast Island .	19.26	20.5	16.0	25.0	9.0
Middle Bass....	16.01	16.85	13.5	20.2	6.7
Buckeye Isl....	15.6	16.5	12.4	20.6	8.2
Rattlesnake....	13.89	15.65	11.3	20.0	8.7
Sugar Island...	14.62	16.5	12.4	19.9	7.5
Hen Island.....	14.87	16.5	12.4	20.6	8.2

The mean lengths follow the same trend as the average lengths and presents the same deviations from the average obesities.

The greatest maximum length, 27 mm., is found at Gibraltar and the least, 19.9 mm., at Sugar Island. The greatest minimum length, 16.8 mm., occurs at Gibraltar, and the least, 11.3 mm., at Rattlesnake.

The greatest variation in length, 10.2 mm., occurs at Gibraltar, the least, 6.7 mm., at Middle Bass.

The specimens from Squaw Harbor and Gibraltar are exceptionally long for *Goniobasis livescens*. In a private letter to Dr. Krecker, Dr. Bryant Walker stated that the *Goniobasis livescens* he (Dr. Krecker) sent him, were the longest he had ever seen, with the exception of specimens from Presque Isle, and that these specimens almost warranted description as a special variety.

Table III shows the width, mean widths, maximum widths, minimum widths, and the difference between the last two.

The average widths differ from the order followed by the average obesities in case of Middle Bass and Rattlesnake. The mean widths vary in the case of Hatchery Bay, Middle Bass, and Rattlesnake. The maximum widths vary in the case of Squaw Harbor, Gibralter, Middle Bass and Rattlesnake. The minimum width differs in the case of Hatchery Bay, Middle Bass and Rattlesnake.

TABLE III.

Station	Average Width in mm.	Mean Width in mm.	Maximum Width in mm.	Minimum Width in mm.	Difference
Peach Point....	7.16	7.25	8.5	6.0	2.5
Old Dock.....	7.13	7.25	8.5	6.0	2.5
Hatchery Bay..	7.08	7.35	8.4	6.3	2.1
Squaw Harbor.	6.95	7.15	8.6	5.7	2.9
Gibraltar.....	7.01	7.35	8.5	6.2	2.3
Ballast Isl.....	8.69	9.0	10.5	7.5	3.0
Middle Bass....	7.25	7.1	8.7	5.5	3.2
Buckeye.....	7.40	7.7	9.4	6.0	3.4
Rattlesnake....	6.60	6.65	8.3	5.0	3.3
Sugar Island...	7.22	7.65	9.0	6.3	2.7
Hen Island.....	7.80	8.25	10.1	6.4	3.7

Not including column five of Table III all the maxima occur at Ballast and all the minima at Rattlesnake. The shells from the former place were exceptionally large and those from the latter were unusually small.

It could hardly be expected that the average lengths and the average widths would run exactly parallel with the average obesities. What I mean is this, that there may be instances where the average obesity increases even if the average width decreases, or that the average obesity may increase even when the average length increases. This is true because the average obesity depends on both the average length and the average width. But as Tables I and II show, this does not happen very often.

More deviations would be expected in the means of either obesity, length or width, since they represent the average of only two individuals in each case. And in the maxima and minima deviations could be still more frequent in as much as they are measurements of only one individual in each case. With this in mind one can easily see how Squaw Harbor can

have the lowest obesity and yet not have the greatest maximum length. Or, that Ballast can have the maximum average width and yet not have the greatest average obesity. Or, again that Rattlesnake, with the least average width, still can have the third largest average obesity.

The average obesity, since it is dependent upon both the average length and the average width of at least one hundred shells in each case, would seem to be the most reliable criterion as far as the results embodied in Tables I to III are concerned.

Table IV is a record of the results obtained on the *Goniobasis livescens* in the Olentangy and the Scioto Rivers near Columbus. It seems to show that there is some difference in obesity in the rivers and that the obesity is correlated with the rate of flow. However, the amount of data is too limited to draw any conclusion.

TABLE IV.

	OLENTANGY			SCIOTO		
Station	Av. L.	Av. W.	Ave. O.	Av. L.	Av. W.	Av. O.
Rapids	15.53	6.37	41.01	17.73	7.11	40.10
Pool	18.8	7.12	37.86	18.29	7.22	39.47

The volume of water in the rapids in the Olentangy was much greater than that in the rapids on the Scioto. This is probably the reason why the difference in obesity in the Olentangy is greater than in the Scioto. Another reason for the small difference in obesities at the Scioto is that, in my judgment, the snails in the pools might at times be subject to draught.

It might be well to point out here that wave action and rate of water-flow expressed in volumes are not quite identical. Wave action is more nearly identical with the rate of flow and the volume of flow combined. The volume of flow might be relatively large, but if its flowing is slowly and steadily, it would jar the snails less than would a much smaller volume if flowing at a greater rate.

DISCUSSION.

On examining Tables I–III it becomes at once apparent that the degree of obesity is very definitely correlated with the degree of exposure to wave action. This is especially well illustrated by the first six stations, namely, Peach Point, Old

Dock, Hatchery Bay, Squaw Harbor, Gibraltar and Ballast. It is again quite striking when any two of the remaining five stations are compared or when any one of them is compared with any one of the first six, but especially when compared with Gibraltar and Squaw Harbor.

The differences in obesity are produced in two ways: (1) in some shells the top is worn off so that several whorls are missing; (2) many shells are very bulbus, which makes the ratio of width to length high.

Before attempting to explain the relation of obesity to exposure some other factors that might limit the distribution and development of *Goniobasis livescens*, or any other gill-breathing mollusk, will be considered. These are: temperature, oxygen supply, Co_2 in the water, nature of substratum, depth of water, and exposure to wave action.

TABLE V.

Station	Squaw Harbor	Gibraltar	Peach Point
Average Temperature.....	75.5° C.	73° C.	74° C.

Temperature cannot be of much direct influence and cannot account for the differences in size and shape of *Goniobasis livescens*. All these stations are frozen over during the winter months and hence the snails must in all cases be able to endure a temperature not above 4° C. The average temperature is probably slightly lower in the more exposed area, because of the water being mixed with water from the deeper and cooler portions of the lake. While the average temperature for Squaw Harbor is, perhaps, more favorable, it is equally true that Squaw Harbor is subject to great diurnal changes in temperature as well as in alkalinity. Temperature readings are here given for the north side of the bar at Peach Point, for Squaw Harbor, and for Gibraltar. These readings were made during July, 1923.

Table V shows the average temperature for the month is very nearly the same, for all the three stations considered. Then in comparing Table I and V, we note that while the average temperature at Peach Point is more favorable than that at Gibraltar, the average obesity at Peach Point is 5.9% greater than that at Gibraltar. If temperature were a determining factor, we would expect that the obesity at Gibraltar would be greater than at Peach Point.

Table VI brings out the great daily variations in temperature in a protected place, like Squaw Harbor, and the relatively small variations in a more exposed place, like Peach Point. The conditions at Peach Point and at Squaw Harbor may be taken as representative of all exposed and protected stations respectively—provided the depth of the water is the same.

If it is true that a constant temperature is more favorable for growth and normal development than one that varies considerably, it would appear, as far as temperature is concerned, that Peach Point is the more favorable environment of the two stations, for here the variation is only 4° C., while it is 16° C. at Squaw Harbor. The difference in the amount of variation is easily explained; the water at Peach Point, though shallow, is continually mixed with water from the cool portions of the lake, while the water at Squaw Harbor, also shallow, is ordinarily not mixed with lake water.

TABLE VI.

Station	Time of Day	Temperature	Ph.
Squaw Harbor	9 A. M.	70° C.	8
	11 A. M.	78° C.	8
	4 P. M.	86° C.	9
Peach Point	10 A. M.	72° C.	8
	11 A. M.	73° C.	8
	4 P. M.	76° C.	8

Note: These readings were taken July 9, 1923.

Temperature has undoubtedly an effect upon the rate of growth. Howard has shown that the growth in fresh-water mussels occurs during the warm summer months. This is likely also true for *Goniobasis livescens*, but the variations in temperature as shown above are hardly sufficient to produce any change in the rate of development. Much less could it be the cause of the remarkable differences in shape and consequently the obesity.

Temperature could also have an indirect effect through the food supply. That it is not a limiting factor in this respect is evidenced (1) by the growth of filamentous algae on the stones where snails were collected, (2) in most instances the shells were heavily covered with algae, and (3) that if they feed on plankton at all—which according to Baker is doubtful—my plankton studies in (23) show that diatoms, desmids, and

several unicellular algae are quite abundant even in places that are exposed to the full force of the waves from the open lake, as for instance, the western shore of South Bass.

The oxygen supply cannot be a limiting factor, because most stations are in shallow water, and where this is not the case, as at Old Dock, the snails live near the surface of the water. The wind stirs the water sufficiently to keep it well supplied with oxygen.

Carbon dioxide may affect Mollusks in two ways. If present in large quantities it becomes toxic and thus kills them. Again, if mollusks live in soft water or in water containing only small amounts of Ca Co_3 and Co_2 is present in considerable quantities, it might combine with Ca Co_3 of the prismatic layer, (when the periostrum is ruptured), and the nacre to form the soluble Ca $(HCO_3)_2$, (Cooker, Shira, Clark, and Howard); (Hegner). Ca Co_2 is abundant in all these stations.

My determinations of the concentrations of free CO_2 and the hydrogen ion in this region of Lake Erie show that the water contains at the most very minute traces of CO_2. This of course would be expected, for the water is shallow and almost continually stirred by slight winds, making it easier for the CO_2 to escape. Again as the temperature increases, the capacity of the water to hold CO_2 is decreased. The hydrogen-ion concentration in any of these places is not above PH = 8. This means that the water is very decidedly alkaline. Before CO_2 in solution could attack the mineral components of the shell it must neutralize the excess OH-ion of the water. But CO_2 dioxide is not chemically active until it has combined with water to form H_2CO_3, which in turn is ionized to form $H + HCO_3$, and because if it had done this, the H-ion would first combine with OH-ion to neutralize the water, and again because we find the water decidedly alkaline, it follows that an excess of dissolved CO_2 does not exist.

The nature of the substratum is also of great importance in the distribution of mollusks. Adamstone ('21) has shown it to be of importance in the distribution of Mollusca in Lake Nipigon; Cooker, Shira, Clark and Howard have called attention to the importance of the character of the substratum in the case of fresh-water mussels. Howard again in the artificial rearing of fresh-water mussels has ascribed great significance to the nature of the bottom. Krecker ('24) has shown that the substratum is an important factor in the distribution of

Goniobasis livescens. Baker reports *Goniobasis livescens* from 15 stations in Oneida Lake, but in every instant he states that they are found on boulders.

Undoubtedly the substratum does play an important part in the distribution of different species of Mollusca, including *Goniobasis livescens*. But in my opinion it does not account for the great variations in obesities as shown in Table I, column one. Take, for instance, the substrata of Old Dock, Middle Bass, and Hen Island, which are as nearly alike as any three substrata could be. Yet the average obesity at Old Dock is 39.3%, that at Middle Bass is 45.2%, and that at Hen Island is 42.44%. Again the substratum at Sugar Island, on account of the many large boulders, is really more favorable than the substratum at Buckeye. Still the average obesity at Sugar is 49.3%, while that at Buckeye is 47.4%. Apparently the substratum does not account for the differences in obesities.

The depth of the water is another factor that may limit the distribution of Mollusca and they are accordingly divided into deep water species and shore species. No variations in my snails can be ascribed to a difference in depth, since all collections were made in approximately the same depth of water. The water at all the stations except Old Dock does not vary more than two feet in depth, and even here the snails were near the surface.

Food is not only an important factor, but it may become a limiting factor for any form of life, especially animal life. Yet it is not probable that the difference in obesity could be explained on a basis of food. It is certain, as Colton has shown, that a shortage of food may produce dwarfing, but as far as I can tell there exists no shortage of either organic or inorganic food. It has already been emphasized in connection with temperature that organic food is abundant. And under the discussion of CO_2 it has been shown that there is no shortage of Ca Co_3. Yet if there were a shortage of $CaCo_3$, the only difference that would be likely to be produced would be a reduction in the thickness of the prismatic and the mother-of-pearl layers, and would not necessarily affect the shape nor the length of the shell. Even a total absence of these layers would not produce a great difference in the ratio of the width divided by the length. Incidentally it happens that the obesity is least in Squaw Harbor where the alkalinity is greatest.

Wave action. Adamstone ('21) concludes that aside from the food supply the degree of exposure to wave action is the principal factor that limits the distribution of mollusca in Lake Nipigon. Krecker ('24) has shown that the distribution of *Goniobasis livescens* is definitely correlated with wave action. I have had ample opportunity to confirm Krecker's conclusions. Baker states that in Lake Oneida *Goniobasis livescens* are more abundant on a bouldery shore than on a bouldery point. Perhaps this could be explained on a basis of exposure.

My results as recorded in Table I, show as far as they go conclusively, (1) that variations in obesity are correlated to the exposure to wave action, and (2) that the obesities are directly proportional to the degree of exposure to wave action, i. e., the obesity is increased whenever the degree of exposure is increased.

This is in line with the results obtained by Ball ('22) in the case of certain species of fresh-water mussels. Ball found that in certain species the obesity increased, with an increase in the volume of water flow. It is perhaps well to note that wave action and volume of water-flow, as used by Ball, are comparable, but are by no means identical. Jarring and vibrations play a much greater part in wave action than it necessarily would in a stream. This would probably make no difference in the case of mud-burying mussels, but it makes a big difference for *Goniobasis livescens*. My results also agree with those obtained by Colton ('22) in the case of the Dog Whelk, as indicated in the introduction.

If obesity is a function of wave action, how is this relationship brought about? It has already been indicated that the great differences in obesities are produced in two ways, (1) in some shells in the more exposed situations, the apex is worn off considerably, and (2) the shells in the exposed situations are very bulbous at the base and then taper sharply while in the protected situations the base is no more bulbous than any other part of the shell and they taper off very gradually. The wearing off of the apex accounts only for a small amount of the increase in obesity, for even some specimens from the most protected stations have the apex worn off. It is true, as Table II shows, that there is a decrease in the average lengths in the more exposed stations. But this decrease in lengths is due largely to the fact that in specimens from the exposed places the whorls above the first one are very much narrower than

corresponding whorls of the specimens from the protected stations. Again in referring to Table III, we note that the increase in the ratio of the width to the length is due not alone to a decrease in length, but also to a decided increase in the width.

Number (1) can easily be accounted for by the mechanical action of the waves—the wearing off of the apex is analogous to the erosion of rock strata by streams. Number (2) is either a germinal difference or it is the result of the direct effect of the environment—in this case thought to be the wave action.

The assumption that these variations in shape are hereditary and that the whole thing is a matter of natural selection is open to the following objection. If it is a matter of a survival of the fittest—best fitted to the environment—why is there so little overlapping in the protected situations?

Why are practically all the shells at Squaw Harbor and Gibraltar for example elongate, while all the shells at Middle Bass or Sugar Island are of the bulbous or obese type? If conditions at Gibraltar or Squaw Harbor are favorable for the snails with a long slender shell, why would not that same environment be favorable for snails with a short bulbous shell and a larger foot? (The ratio of the length of the aperture to the width of aperture in Squaw Harbor is 167.0, while at Sugar Island the same ratio is 150.2).

Again the assumption that the differences are environmental variations is open to criticism for lack of experimental evidence to that effect. It is true Colton has shown that various environmental factors—see introduction—may cause dwarfing, but it has not been shown for *Goniobasis livescens*. The final answer then will have to wait until breeding experiments can be carried out to show whether these variations are hereditary or not.

Supposing that these variations are not hereditary and that they are the result of wave actions, how could this relationship be explained? The effect of wave action is perhaps of two kinds, (1) it may be the cause of dwarfing, i. e., a snail develops so slowly that it might never develop the full number of whorls. (It is pointed out by Colton that shells of the same size, but of different age have the same number of whorls, (2) it may change the direction of growth; shells instead of becoming long and slender become short and obese.

Just how wave-action produces this effect is not known, neither is it known how other environmental factors produce temporary variations. But it is entirely possible that this jarring coming at some critical period in the development changes the direction of growth.

Summary.

1. The average obesity is directly proportional to the degree of exposure to wave action.

2. The differences in obesity are due to a wearing off of the apex and to a difference in the shape of the shell. The latter accounting for the main part of the difference.

3. The more obese shells have a larger aperture and hence a larger foot.

4. What is true as to the relation between obesity and exposure to wave action in the lake is probably also true for the Scioto and Olentangy rivers near Columbus.

5. It cannot at present be decided whether these differences in shape are due to heredity or whether they are the result of the direct effect of the environment.

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FOOD PLANT AND HABITAT NOTES ON SOME NORTH AMERICAN SPECIES OF PHLEPSIUS.

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A systematic treatment of the North American species of *Phlepsius* by Prof. Osborn and Dr. Lathrop appeared rather recently.* This is an excellent paper for the separation and identification of our North American species. Probably in an attempt to abbreviate the paper, food plant notes and ecologic data were omitted. The present treatment is undertaken in order to give some notes on personal observations in the field and to show some of the interesting diversities in habitats of the members of this genus.

Probably one of the most interesting groups of the genus and one which is apparently quite distinct in coloration and food habits from the other species, contains the so-called "banded" species of *Phlepsius*. This group includes those forms which are definitely marked by cross bands of darker brown coloration giving the insects the general appearance of markings of alternating light and dark brownish transverse bands. In all cases where food plants have been definitely determined for these species they have been found feeding upon some species of pine. *Phlepsius tigrinus* and *Ph. franconianus* occur together, frequently being found on the same tree or limb. Mr. Knull has collected both species from White Pine, *Pinus strobus*, in the Allegheny Mountains of Pennsylvania. The writer has also secured them from this food plant in Pennsylvania and in Ohio has taken them abundantly on *Pinus rigida* and *P. virginiana*. In Ohio *Ph. tullahomi* has frequently been taken with them also. In a previous paper† the writer pointed out that this species was not a tree inhabitant and that it occurred on *Andropogon*. This statement was made in error, as more recent investigation has shown that minute seedlings of *Pinus virginiana* and *rigida* were growing in what seemed to be a pure *Andropogon virginicus* association. The seedlings were only a few inches in height and completely hidden by the clumps of *Andropogon*. Although most abundant on these

*Ann. Ent. Soc. Amer. Vol. 16, p. 310, 1923.
†Conn. Geol. and Nat. Hist. Surv. Bull. 34, p. 130, 1923.

small succulent pines, they also occur and have recently been taken in nymphal and adult stages from older trees.

The same mistake was made at first regarding the food plant of *Ph. palustris*. Seemingly it was swept from a heavy sedge, *Juncus megacephalus*, but close observation revealed in that case also small seedlings of *Pinus palustris* and it was afterwards taken from larger pines where no sedges occurred. This species is by far the largest and most robust of the banded group. *Ph. slossoni* and *Ph. lippulus* are both southern species and live on pine. Food plant records to date, however, show them to be confined to different species of pine. *Ph. slossoni* has been taken only from *Pinus caribea* and *Ph. lippulus* only from *Pinus palustris*. Further observations may show a wider range of food plants for each of these species. *Ph. strobi* receives its name from the white pine on which it lives. This species has long been confused with a species of *Eutettix*, feeding on *Chenopodium*, which error has recently been pointed out by Prof. Osborn. *Ph. granticus* is also reported by Lowry as occurring on pine in New Hampshire.

A number of species of the genus also occur on the floor of the pine woods. In Florida several species live in this habitat, some of which are found farther north. *Ph. floridanus* and *Ph. attractus* occur on the fine short grasses of the pine forest floor in well drained areas. *Ph. nudus* and *Ph. tubus* occur on similar small grasses in open pine woodland. *Ph. pulchripennis* is found for the most part under pine woodland conditions, but on herbaceous growth and where the soil is apparently more moist. In addition it occurs on grasses bordering the everglade areas and was taken from grasses in open portions of the everglade hammocks. In these three habitats the conditions under which it occurs are similar. *Ph. distinctus*, another grass species of the open pine woods, was found only where the growth was very luxuriant and the woods sufficiently open to favor a heavy growth of the herbaceous layer and to present the appearance of a savannah. The food plant could not be determined.

Present records would indicate that very few species are known to live on trees or shrubs other than pine. *Ph. tinctorius*, probably an imported species, is known only from the New York, Newark, N. J., area, where it occurs on *Aralia spinosa*. *Ph. marmor*, known at present only from Manitoba, is reported from *Juniperus horizontalis*.

The great majority of the species are grass feeding and occur under varying conditions. In addition to those mentioned as occurring on the herbaceous growth of the pine woodland floor, several are abundant in the swamp and marsh. Two species especially are common in the Florida everglades. *Ph. planus* is abundant on *Panicum hemitomum*, the maiden cane, and *Ph. cottoni* occurs in the *cladium effusum*, sawgrass, association. *Ph. latifrons* also occurs in the everglade region on the moist prairies, but is found in more northern states as a meadow species.

Several different conditions are found in the fresh water swamps and marshes of the northern states. From field observations probably no species of *Phlepsius* could be designated as a true swamp form. *Ph. solidaginus* would approach this condition quite closely, however, as it is common on the tall grasses of the fresh water marsh in a mixed association of *Carex-Phragmites*. *Ph. ramosus* has been taken from a similar habitat, but no specific data was obtained regarding the food plant. *Ph. fuscipennis* and *Ph. collitus* have been found very abundantly on short growths of *Juncus*, *Eleocharis obtusa* and *Scleria verticellata* at the margins of fresh water lagoons, where the small waves of the lagoon keep the sandy soil very moist and produce a very humid habitat. *Ph. nebulosus* has also been taken abundantly from the same plants, but where they were growing under different conditions. In this case the water had receded in the old lagoon basin so that a somewhat drier condition prevailed and the plants had formed a mat or turf.

At least two species are definitely associated with the bog habitat. Prof. Osborn has reported collecting *Ph. maculellus* on fine grasses in the bog association. *Ph. ramosus* also occurs in boggy areas and has been taken from clumps of grass growing in a mixed *Sphagnum-Tamarack* habitat.

A few species undoubtedly live most abundantly under heath conditions. *Ph. fulvidorsum*, although occurring in woodland areas, is found in greater abundance on one of the herbaceous plants in the heath association. It occurs in an association where *Smilax* sp., *Vagneria* and associated plants are found. *Ph. cumulatus* is another and more typical heath species, but is found under entirely different conditions from the preceding. It has been collected abundantly from mats of a pure association of *Arctostaphylos* (bearberry) which forms a portion of the herbaceous ground layer of plants in the northern conifer forests.

The character of the meadow may vary to a great degree. It may be a high, well drained area or a low moist meadow and as a consequence the type of plant and the humidity factor may vary decidedly. For this reason a larger number of species might be placed as meadow inhabitants. Several species are common in different types of meadows. In the northern states *irroratus*, *truncatus*, *collitus*, *decorus* and *tennessa* are found abundantly. The first three of these are very common. In the extremely northern states and Canada *Ph. apertus* is a common meadow species. *Ph. superbus* and *Ph. excultus* are abundant meadow species in certain localities, especially in the southern states.

Large areas of upland pasture and grazing land are covered with *Andropogon virginicus* as the principal species of grass. In this association *Ph. carolinus* and *Ph. cinereus* are found rather abundantly. *Ph. collinus* occurs in the same areas, but probably lives upon the small patches of *Aristida* which are constantly being invaded by the *Andropogon*. In some places it is also found on the washed areas where the *Aristida* is usually the pioneer plant to grow upon these denuded spots. *Ph. altus*, superficially resembling the former species, occurs on the short grasses of the western plains.

Open woodland areas of the deciduous forest, especially in mixed mesophytic forests where the humidity is rather high and there is a rich growth of herbaceous plants, furnish the proper habitats for several species. Of these might be mentioned *Ph. particolor*, which has been taken only in a very restricted habitat of this type, where short grasses together with *Luzula campestris*, *Sanicula canadensis*, *Viola blanda* and similar plants occur in a mixed hemlock-beech woodland. *Ph. incisus* occurs in the same habitat, but is found living under more varied woodland conditions. *Ph. decorus* and *Ph. fulvidorsum* may also occur under woodland conditions, but the relative degree of humidity may be much lower in the case of these latter species. *Ph. majestus*, also a woodland species, occurs on tall grasses growing in moist areas in rather dense shade where only a few herbaceous plants are found.

This data collected while observing field conditions of these insects in the Eastern U. S., shows a great diversity in food plants and types of habitats. If similar data could be brought together for the western species as well, it would probably show even a greater diversity of conditions, especially in the case of the mountain species and those of the arid southwest.

THE LIMESTONE CAVES AND CAVERNS OF OHIO.

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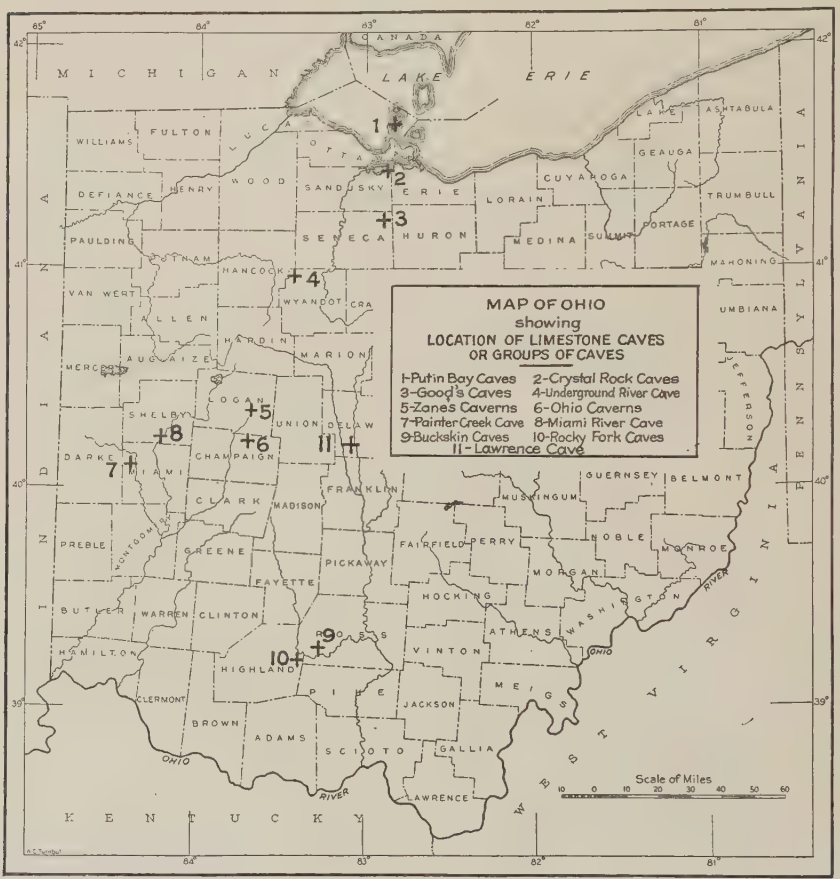
INTRODUCTION AND ACKNOWLEDGMENTS.

The limestone caves and caverns of Ohio, with two or three exceptions, have not previously been described. The presence of such natural phenomena at various places in the State has been known, but aside from the locations of the larger ones no definite information, especially under one head, has been available. While no Ohio cave known is as much as a half mile in length, nevertheless many of them present features worthy of description, and all have at least local interest.

This paper was prepared under the direction of Dr. J. A. Bownocker, who outlined the problem, offered valuable advice during the progress of the field work, and aided greatly in the preparation of the manuscript in its final form. The writer takes this means of expressing his sincere thanks and appreciation for the assistance. The Geological Survey of Ohio provided funds for field expenses and for the tracing of maps. I wish to thank Dr. J. E. Carman for the stratigraphy of the Monroe, Dr. August F. Foerste for information on the Niagara of the Rocky Fork region in Highland County, and Dr. William J. McCaughey for advice on the deposits and help in mapping Zane's Cavern. Assistance which was necessary in surveying all the caves was given by Messrs. Irvin C. Colman, Paul E. Fitzgerald, Wendall Camp, and P. J. Harris, friends of the

writer. The rough field maps were traced, section-lined, and lettered by Prof. W. D. Turnbull, and the fine quality of his work is self-evident.



Location of the Caves and Their Geological Horizon.

The location of the caves is, in a broad way, in the western half of the State from Put-in-Bay in Lake Erie on the north, to Highland County on the south. (Map 1). Stratigraphically, they occur from the base of the Niagara (Silurian) to the top of the Delaware (Devonian). The Ordovician limestones of the State are too thin bedded and argillaceous to permit the formation of caves.

SECTION SHOWING THE GEOLOGICAL HORIZON OF OHIO CAVES AND CAVERNS.

- Devonian System
  - Delaware limestone, Lawrence Cave
  - Columbus limestone
    - Ohio Caverns
    - Zane's Cavern
    - Good's Cave
- Silurian System
  - Monroe Series
    - Bass Island formation
      - Put-in-Bay Caves
      - Crystal Rock Caves
      - Buckskin Caves
  - Niagara Series
    - Underground River Cave
    - Miami River Cave
    - Painter Creek Cave
    - Rocky Fork Caves

The limestone caves of the State, with the exception of those of Rocky Fork, are located where there have been at least two periods of continental glaciation, and thus the relief is not great. Such a condition is not favorable for the formation of vast caverns with many levels, such as those in Kentucky and Indiana. Perhaps the advance of the great ice sheets removed some existing caves entirely and obliterated evidence of others.[1] Doubtless additional caves will be discovered in Ohio from time to time, due to the collapse of roofs and openings becoming evident which are now filled with glacial drift.

It is probable that most, if not all, of the fissure type of caves in the State antedate, at least in their beginning,[2] the first advance of the glaciers into the area. The pre-glacial origin of the Rocky Fork Caves is more fully discussed under that heading. The time necessary for solution of the limestone, and that for the formation of the deposits, seems longer than post-glacial time.

TYPES OF CAVES.

The limestone caves of Ohio are of two types. Most of them belong to the fissure variety, produced by solution of the rock usually along joint planes. Their origin is discussed later. The second variety is that in which the floor and roof seem at one time to have been in contact, and is best typified by those on Put-in-Bay. No satisfactory name has been proposed for this, and for convenience, it will be referred to in this paper as the "Put-in-Bay" type.

[1] Hubbard, Geo. D., Geol. Surv. Ohio, 4th Ser. Bull. No. 14, 1911, pp. 61–65.
[2] Ibid., p. 63, also Hills, T. M., "Reames Cave," Ohio Jour. Science, Vol. XVI, No. 6, pp. 209-215.

The caves on Put-in-Bay, those in Crystal Rock Park, and Good's Cave belong to this type. Others described are of the fissure or joint-plane type. Good's Cave, while presenting an aspect somewhat similar to those of Put-in-Bay, seems to have had a different origin, which is given under its description. The origin of the Put-in-Bay and Crystal Rock Caves will be taken up after the description of the former.

Formation of Caves and Their Deposits.

The fissure or joint-plane type of caves has been formed by solution during a long period. Atmospheric water falling as rain[1] unites with the carbon dioxide (CO_2) of the air and forms weak carbonic acid,

$$(H_2O + CO_2 = H_2CO_3)$$

This acidulated water in contact with limestone forms calcium bicarbonate, $CaH_2(CO_3)_2$

$$H_2CO_3 + CaCO_3 = CaH_2(CO_3)_2.$$

In this manner the rock is dissolved and carried away by seeping and flowing waters. The action is usually hastened by humic acid which has been taken up by the water in passing through decaying vegetable matter before reaching the limestone. The crevice through which the water so charged seeps is thus gradually enlarged until a cave is formed. When a stream flows through the opening, action is much more rapid, due to erosion. This, while important in the formation of some of the larger caverns of the country, does not seem to have been very influential in the Ohio caves. In many of the caves of this State all action toward further enlargement has ceased, in some places because of drainage changes by the great ice sheets, and in some from other causes. These caves are said to be "dead," and this feature is mentioned in the description of several of them.

Many limestone caverns are partially filled with secondary deposits called travertine in this paper. In places these are in sheet-like deposits, and elsewhere in the form of stalactites and stalagmites. Their formation is the reverse of that for the solution of primary limestone, the reversion taking place when the water, carrying calcium carbonate in solution, which

[1]Blatchley, W. S., "Indiana Caves and Their Fauna," Twenty-first Annual Report, Dept. of Geol. and Nat. Resources of Indiana, 1896, pp. 121–123.

seeps into the passages, evaporates and deposits the contained mineral matter.[1] Where the water flows over the walls, the deposits are sheet-like in character, but where it drips from the roof a stalactite, which resembles an icicle, is the form taken. When the water dripping from the roof is not entirely evaporated before it falls to the floor, a mass is built up below the stalactite, which is broader and called a stalagmite. With continued action of this sort, the stalactite grows slowly downward, and if conditions are such that a stalagmite is formed underneath, the two may finally coalesce, forming a column or "stalacto-stalagmite."[2] The mineral-laden waters then flow over the column, slowly increasing its size, and these deposits are analogous to the sheet deposits found on the walls.

The color of these deposits varies from almost transparent and crystal clear material to muddy brown, the latter caused by foreign particles carried by the water in suspension. Beautiful tints caused by iron oxide are often found, varying from faint pink, through salmon and red, to dark brown, according to the amount of iron present. Local variations of coloring matter are often very striking.[3]

When deposition in a cavern has ceased, the travertine assumes a dry and ossified aspect, and if the action has ceased for a long time the deposits may look very much like badly weathered bone. The deposits of most of the Rocky Fork Caves are of this character.

The argillaceous matter in the limestone of these caves, being insoluble, is left behind as residual clay. This may cover the floors and walls to depths of six inches or even more. The caves in the Cedarville dolomite of the Niagara series (particularly those of Rocky Fork and the Miami River) show this character.

Methods of Mapping.

While the mapping of each cave presented a more or less particular problem, the procedure was similar with each, with certain minor exceptions. A plane table, 15 inches square, with a light tripod was used. For orienting, a small compass

[1]Deposits from Zane's Cavern were studied in thin section and in powder with the petrographic microscope, and the material was found to have the properties of calcite rather than those of aragonite, the biaxial form of $CaCO_3$.

[2]Blatchley, W. S., "Indiana Caves," Twenty-first Annual Report, Dept. of Geol. & Nat. Resources of Indiana, 1896, p. 123.

[3]Hills, T. M., "Reames Cave," Ohio Jour. Science, Vol. XVI, No. 6, 1916, pp. 209–215.

sunk in one corner of the table was found to be accurate enough for the purpose but this was checked occasionally with a larger instrument of proven reliability. The magnetic declination in the areas mapped varied from one-fourth to three-fourths of a degree west. A scale of 20 or 40 feet to the inch was the one most employed for the original maps, although variations of these, as can be seen from certain of the maps, were sometimes found to be necessary or advisable. A small peep-sight alidade was employed, as the poor light and the small spaces precluded a larger plane-table and a telescopic alidade. An ordinary tape was used and measurements were usually plotted to the nearest one-half foot, as closer work would not be evident on the maps.

The major points of the map were fixed by radiation or traverse, triangulation sometimes being used as a check. After fixing the major points the walls and passages were sketched with considerable care. An assistant carried a light, usually a flashlight of the common focusing type, although sometimes a candle was used to take bearings on. The work at the plane-table and the sketching was done by the author, with the exception of one or two of the caves. In some of the larger caverns which were lighted by electricity, the work was not particularly difficult, but in most of the caves which were not so lighted, the mapping proceeded more or less slowly. Where the roof was very low, the top of the plane-table was detached, and in some of the very lowest passages, traversing proceeded very slowly because the drawing board had to be pushed ahead of the instrument man, bearings kept, and one end of the tape handled. When it is remembered that where passages were this low, they were frequently covered with mud, and water dripped from the roof, the difficulties in producing an accurate map may be appreciated. Where a cavern had two entrances, or other means of checking were present, this was done, and proved that the maps were almost always as accurate as could be made with the instruments at hand.

The maps in the field were drawn in pencil and later inked. The draftsman traced them, adding the section lining, lettering, borders and so on. Where cross sections are shown, they have been made in the field, or from notes that were later plotted in the office.

On account of the relatively small size and the comparative obscurity of most of the caves in Ohio, few amazing stories as to

size and extent are current about them, as has been the case with some of the more famous caverns of the country.[1] However, figures given locally as to size and extent of even the smaller caves may be very greatly exaggerated, some shrinking from miles to hundreds of feet on measurement. The veracity of the writer has upon occasion been seriously questioned when the length of certain caves has been given as only a few hundred feet instead of the reported mile or two which the average layman has thought it to be. Due account must be taken of the great apparent increase in distances underground, when the only light may be a small flashlight or a feeble candle and the progress is made lying flat, slowly pulling oneself through the mud and slime with which the floors of some of the caves are covered. The pool in Wet Cave in the Rocky Fork Group is commonly supposed to be "bottomless," but a strong focusing flashlight reveals the bottom, which certainly is not more than 20 feet below the surface.

Put-in-Bay Caves.

South Bass Island is one of the larger islands in Lake Erie which is within the boundaries of the State of Ohio. Together with Middle Bass Island and North Bass Island it makes up Put-in-Bay Township of Ottawa County. The island is four miles from the Catawba Island portion of Danbury Peninsula, the nearest point on the mainland. The entire island is incorporated as the village of Put-in-Bay, and this name is used interchangeably with that of South Bass Island. It is three and one-half miles long and a mile and a half wide at the maximum, the area being a little more than two square miles. The trend of the island is in a north-east and south-west direction. The surface is very slightly rolling, the most noticeable topographic feature being the many sink holes, some of which are more than two hundred yards across, but which are rather shallow.

The bedrock of most of the island is the Put-in-Bay dolomite, a member of the Bass Island formation of the Monroe series. It is thus Silurian in age. The member underlying the Put-in-Bay outcrops about 20 feet above water level along the southwest side of the island. This is the same member as that which contains the gypsum beds of the mainland. It should be the time equivalent of the Tymochtee although it is more shaly than typical Tymochtee.[2]

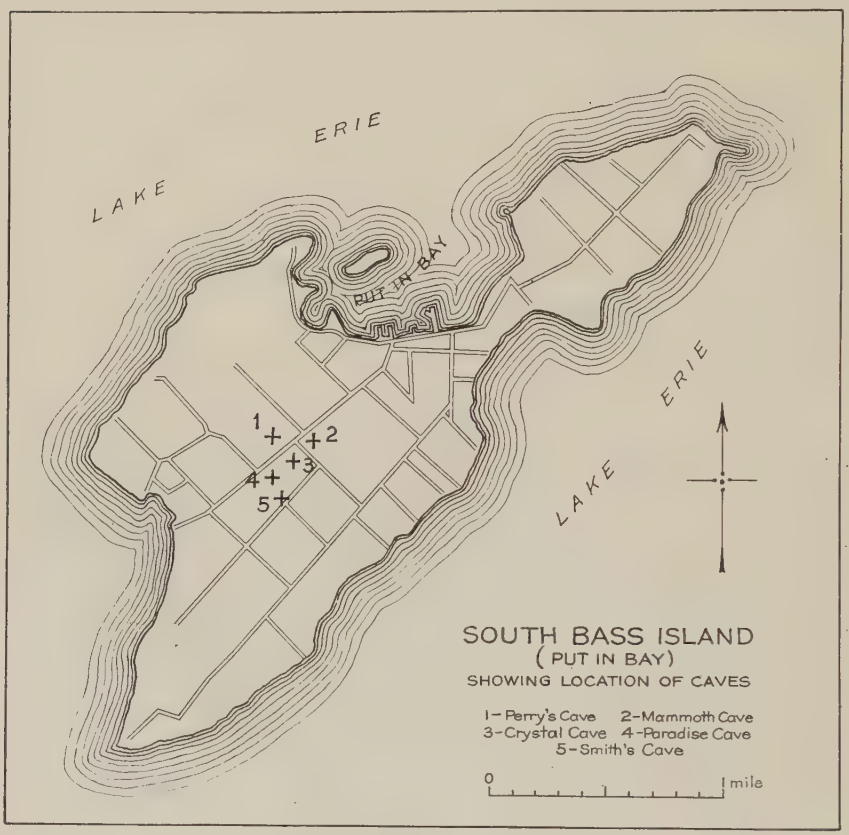
Considerable historic interest attaches to the island in that Commodore Oliver Hazard Perry used Put-in-Bay as a base for his fleet during a part of the war of 1812. It was from this harbor that he sailed for the memorable Battle of Lake Erie on August 12, 1813. The largest

[1]Hovey, Horace G., "Celebrated American Caverns," pp. 18–21.

[2]Carman, J. Ernest, Personal communication, May 14, 1925.

cave on the island is called Perry's Cave, because it is popularly supposed that it was discovered by him, and used as a powder magazine.

The drainage of the entire island is underground, showing that the limestone is honeycombed with subterranean passages. Several openings are known which give access to caves, four of which are of sufficient size and importance to be attractive to the thousands of tourists who visit

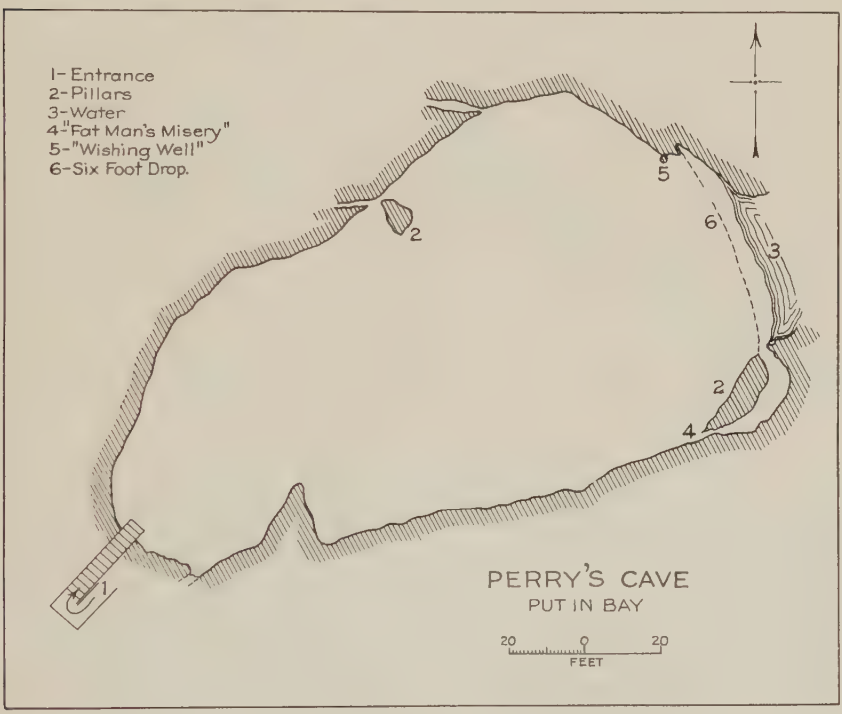


the island during the summer. These have had steps built to facilitate entrance, are electrically lighted, and during the summer have guides to conduct visitors. In addition to the four caves which are regularly open there are several others which are smaller, and which are not often visited. Some caves which were known at one time are no longer open, the entrances having been filled by natural means, or in some cases by the owners. An opening into a cave is usually regarded by a farmer as a liability, on account of the danger to stock, and consequently many have been filled up. The origin of the caves will be discussed after the descriptions.

PERRY'S CAVE.

Perry's Cave has the most traditional and historical background of any on Put-in-Bay Island. It is located about three-fourths of a mile southeast of the harbor, near the public road. The entrance is covered by a large building, formerly used as a dance hall. The entrance has been much enlarged, a concrete stairway affording means of descending into the cave the floor of which is 31 feet 6 inches below the surface.

The cave is roughly oval in shape. It is highest near the center where the roof is nine feet above the floor. To the northeast the floor



descends sharply for six feet and farther on water covers it. This was not measured but it is reported to be 65 feet deep. About 40 feet farther to the northeast the roof meets the water. Interesting to report, the water in the cave rises and falls with that of the lake; in each it stands about two feet higher after a strong northeast wind. Heaping up the water along the shore increases the pressure and this raises the water level in the cave, but no circulation was observed in it. Water is constantly dropping from the roof.

The floor and roof were at one time covered with stalactites and stalagmites, but all of the former and most of the latter have been removed. The few remaining stalagmites are rather large, and to this fact they probably owe their preservation. The roof is covered in most

places with a deposit of travertine, and the floor in some places has more than a foot of this material. The floor and roof are rather flat, any local undulations of the floor being matched by corresponding ones in the roof, that is an elevation of the floor has a corresponding depression above it and likewise a depression of the floor has a projection in the overhanging roof. At the northeast wall, marked "Fat Man's Misery" on the map, a large block of stone has fallen from the roof, one end resting on the floor, and the other remaining against the roof. One end of the rude archway thus formed is rather narrow, hence the name.

The attendant and caretaker of this cave, John Gangwisch, has lived 53 years on the island, and has held his present position for the past 39 years. He places no credence in the popular story that Commodore Perry hid his troops there before the memorable battle in 1813. It is probable that Perry knew of the cave, and may have stored some of his supplies there during the time his fleet was anchored in Put-in-Bay. Nevertheless the cave would seem to be a very damp place in which to store gunpowder. Mr. Gangwisch found several arrowheads, stone axes, and two stone pipes under a stalagmite which he removed years ago, indicating the use of the cave by Indians, thus definitely disproving the tradition of the original discovery by Commodore Perry. However, his reported association has given the cave its name. The cave is visited every year by thousands of people. Electric lights are provided, and an admission fee of twenty-five cents is charged.

Mammoth, Crystal, and Paradise caves, owned by Mr. Gustav Heineman, are located just across the public road from Perry's Cave, the entrances being within two hundred yards of each other.

MAMMOTH CAVE.

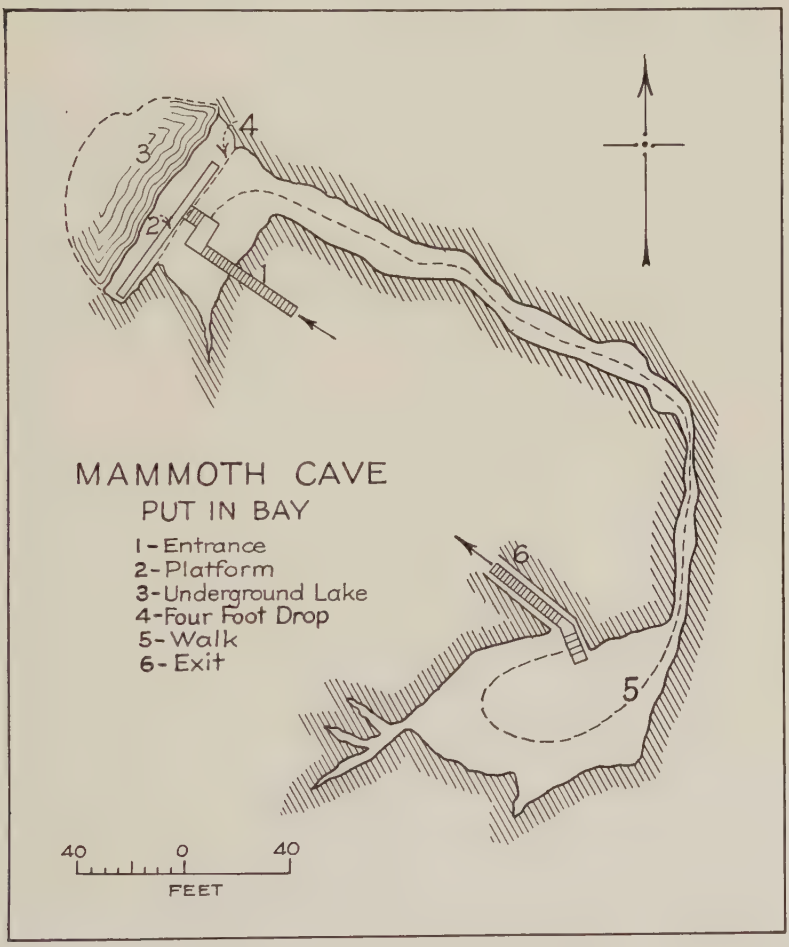
The presence of Mammoth Cave has been known since the coming of the white man to the island. Indications of its use by the aborigines will be mentioned later. This cave has two openings; tourists enter at one and depart at the other. The northwest opening measures 36 feet vertically, and at a point indicated on the map there is an abrupt descent of eight feet more. Ten feet beyond this is the shore of what is popularly called an underground lake. The water deepens gradually, the roof and water meeting about 65 feet to the west. The level of the water rises and falls as it does in Perry's Cave.

The cave has the shape of a very broad U, with directions and dimensions as indicated on the map. Very little water drips from the roof. The entire cave has a very gentle slope towards the water. The floor is only 16.8 feet from the surface at the southeast entrance, in contrast to the 44 feet between the floor and the surface of the ground at the northwest opening.

The roof is covered in many places with a deposit of travertine. A few small stalactites, mostly one-half inch in diameter and two inches long, are present. The stalagmites are not nearly so numerous, but are much larger, as is generally the case. Some of these have been assigned fanciful names, according to their supposed resemblance to an animal, such as "Alligator," "Turtle," etc.

The height of the cave averages from three to four feet, except at the east entrance, where it is 15 feet. A pathway has been excavated to a

depth of from two to three feet so that visitors may walk upright except in one or two places. The floor is very slightly rolling, and evidence seems clear that floor and roof must at one time have been together, because the shape of the floor is the opposite of the roof. This is one of the most striking features about the caves on the island, and will be discussed farther on.



Formerly, according to Mr. Heineman, the underground water was the only source of good water on the island. This cave must also have been known and used by the Indians, because Mr. Heineman reports finding many fish and animal bones, as well as deposits of ashes in it. The cave is shown to thousands of visitors annually. It is lighted electrically and is provided with guides. An admission fee of 20 cents is charged.

CRYSTAL CAVE.

Crystal Cave is the most unusual on the island because of its deposits. It consists of two small connected rooms and was discovered by Mr. Gustav Heineman in 1891 when drilling for water. The entrance is about 200 yards southwest of Mammoth Cave, and a plank stairway descends to the floor, which is 30 feet below the exterior level. The cave had an original height of about three feet, but the floor has been excavated so that visitors may stand upright. The cave is dry; even during rainy seasons very little water enters it.

The walls are completely covered to a depth of two feet in most places by beautiful blue celestite crystals ($SrSO_4$). These are very large, usually ranging from eight to fifteen inches in length. They are tabular in form, and belong to the orthorhombic system. The crystal faces are brachypinacoid, prism, brachydome, and pyramid. Some crystals are attached to the matrix by only a corner or edge, and then show the entire crystal form. The appearance of the interior of this cave is that of an immense geode. The crystals, removed from the floor when it was deepened, were sold to fireworks manufacturers for the strontium.

Because of the covering of the interior of this cave, it is impossible to ascertain if the floor and roof "fit," as they do in the other caves of the island.

PARADISE CAVE.

Paradise Cave is only about 200 yards west of Crystal Cave. It is not large, about 30 feet wide and 125 feet long. The entire cave dips 25 degrees southeast, and ten degrees northeast. The height is from three to five feet, but in some places a little more than a foot of the floor, which is 24 feet below the surface, has been removed for a walk.

Water drips from the roof and is always present in the lower part of the cave but its depth is only two or three feet. The water level, as in other caves of the island, fluctuates in wet and dry seasons.

This cave has more stalactites than any other on the island. In fact nearly the entire roof is covered with them or travertine. The largest is advertised to be 36 inches in length, but the others are very much smaller. The floor also is nearly covered with travertine. A few pieces of fallen rock from the roof were found.

As in the other caves of this group, the floor and roof at one time seem to have been together. The explanation for this phenomenon is the same as for the other caves on the island, and it is offered elsewhere.

Many tourists visit this cave during the summer season, but according to Mr. Heineman, it is not as popular as either Perry's, Mammoth, or Crystal Cave. It is electrically lighted, and an attendant is present in the tourist season to act as guide. A wide plank stairway leads from the shelter house at the entrance into the cave. A unique feature is the strong netting on either side of the walk through it. Inasmuch as this is the only cave on the island that has not been despoiled of its stalactites, the owner desires to keep it intact, and this means is taken of doing so. An admission fee of ten cents is charged. Probably this cave has been known from the time that the island was settled.

SMITH'S CAVE.

In the front yard of the property owned by Tillie Smith, a quarter of a mile south of the caves on the Heineman property, there is an entrance to a small cave which has been walled up four feet square with rough stone to a depth of five feet. From the bottom of this well-like entrance, the cave extends downward at a 25 degree angle for about 50 feet. The length is approximately 150 feet, and the width from 50 to 60 feet. Exact measurements were impossible on account of the very low roof near the limits of the cave. The greatest length is north 10 degrees west. The maximum height is five feet, but through much of the cave it is decidedly less. The cave is dry, but in rainy weather some water must find its way in it for small stalactites, usually three inches long and one-half inch in diameter, are present in abundance. The floor, as well as the roof, is almost covered with travertine, an unusual condition because in the other caves some of the floor has been excavated to form pathways and hence the travertine removed, so that visitors could walk upright.

The floor and roof match each other distinctly, that is an elevation below has a depression above, a fact that is more readily observed in this cave because of the lack of alteration by digging pathways and building stairs. Several narrow passageways lead farther downward, but these are too small to permit exploration. It is probable that they lead to water, thus furnishing a means of drainage. No use is made of this cave, nor are data available as to its history or discovery.

OTHER CAVES ON PUT-IN-BAY ISLAND.

The presence of sink holes over the entire island indicates the presence of more caves than are now known. As stated previously, some entrances have been closed. Cottingham[1] mentions two, one on the property of James Duff, and the second near Hotel Victory, but neither was found by the present writer. Since Cottingham visited the island, Hotel Victory has burned, and now (1924) the extensive and once beautiful and park-like grounds have grown up with brush and weeds. The depressions and sink holes are used as a dumping ground for rubbish by the whole island.

Origin of the Put-in-Bay Caves. One of the most noticeable features of the caves on the island is the one already mentioned in which the floor and roof seem to "fit." In other words, the cavity does not appear to have been formed by solution of the limestone in the usual manner that most caves are, but because the floor and roof, which at one time were in contact, have been separated. The cause of the separation has been assigned by Kraus[2] and Cottingham[3] to the change of layers of anhydrite ($CaSO_4$) in the rock to gypsum ($CaSO_4\ 2\ H_2O$). It is then supposed that the gypsum which is soluble in water[4] was removed, leaving the space of the present caves.

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[1]Cottingham, Kenneth, Ohio Journal of Science, Vol. XX, No. 2, p. 38.

[2]Kraus, Edward H., "On the Origin of the Put-In-Bay Caves," The American Geologist, Vol. 35, pp. 167–171, 1905.

[3]Cottingham, Kenneth, Ohio Journal of Science, Vol. XX, No. 2, p. 38.

[4]One part of gypsum in 483 parts of water, Kraus, p. 170.

The expansive force generated by the hydration of anhydrite to form gypsum is very great, and according to Bischof[1] has often been instrumental in deranging stratified rock. According to the exceedingly conservative estimate of Credner[2], the expansion is 33 per cent when the anhydrite changes to gypsum. Other authors place this expansion as high as 62 per cent.[3] Taking the lowest figure, which is more than three times the expansion of water when it changes from the liquid to the solid state, it seems that such force must be enormous and perhaps sufficient to separate beds of stratified rock.

This is the only explanation advanced to account for the formation of these caves, but positive proof of this does not seem to the present writer to have been established. No gypsum is found in the caves. They do not show separation along any bedding plane, with the possible exception of Perry's Cave, but rather separation along gently dipping cracks which however are very irregular.

It is possible that former caverns have existed below the level of the present caves and that the roofs of some of these have collapsed. The level of the lake conceals any evidence that might be obtained along this line, for water is present in the lower parts of almost all of them.

To summarize: These caves referred to as the "Put-in-Bay type" have not been formed by solution of the limestone by percolating ground water. Their floors and roofs were at one time in contact and later were separated. If the roof was raised the application of some agency, such as the hydration of anhydrite to form gypsum, and the subsequent solution of this, produced the caves; while if the floor dropped, some action has operated from underneath, evidence of which is now concealed by the waters of the lake.

Caves in Crystal Rock Park.

Crystal Rock Park is in the northwest corner of Margaretta Township, Erie County. It is marked "Crystal Rock Spring" on the Bellevue Quadrangle, and is located eight miles west of Sandusky, and three-fourths of a mile south of the Lake. The park is owned by Edward J. Martin who operates it for picnic, summer resort, and dance hall purposes. The portion lying nearest the Lake has been allotted for summer cottage sites. One of the features of the park is Crystal Rock Cave.

CRYSTAL ROCK CAVE.

Crystal Rock Cave is the only one in the park which is regularly shown to visitors. It is in the Put-in-Bay division of the Monroe dolomite which is fairly thick bedded, massive, and apparently non-fossiliferous.

A flight of concrete steps leads into the cave. The entrance is 17 feet square, and it is 16.5 feet from the floor of the main room to the level of the ground above. The entrance was originally a sink hole, which has been blasted out to make a larger opening. There are several other sink holes in the vicinity.

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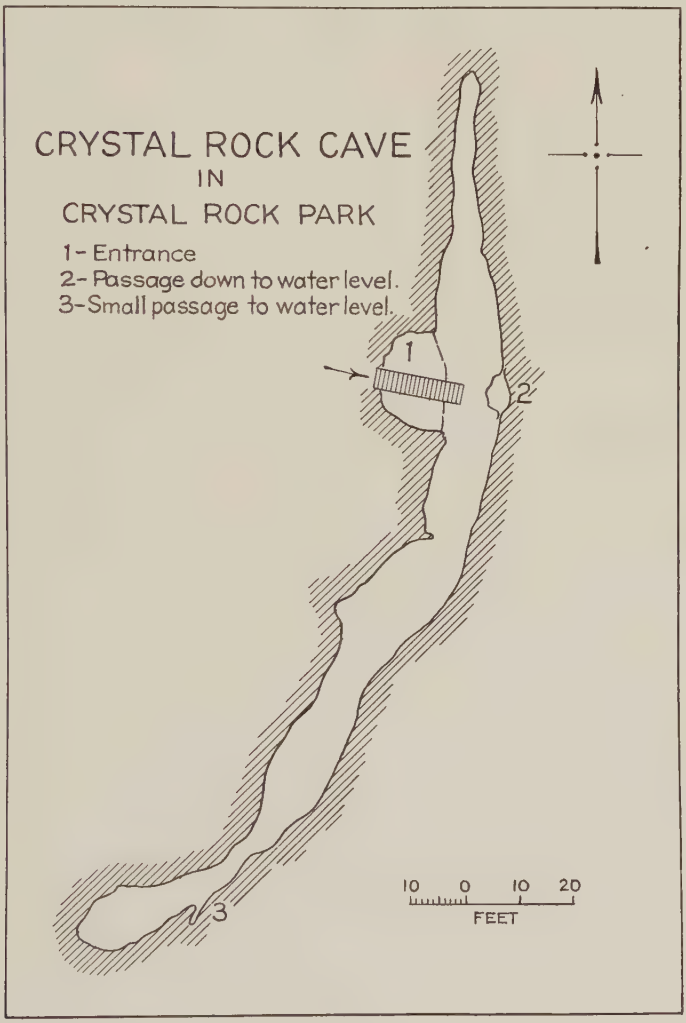
[1]Bischof, Gustav, Elements of Chemical and Physical Geology, English Translation, p. 428.

[2]Credner, Hermann, Geologie Neunte Auflage, p. 96.

[3]Kraus, p. 168.

The main room is approximately 40 feet long and 20 feet wide, and is the only portion ordinarily visited. Here the roof is from four to six feet high. Directly opposite the entrance is a narrow passage about 30 feet long, which descends about 10 feet vertically in that distance.



Beyond the narrow entrance this passage widens a little, being large enough to hold a small electric water pump and pressure tank, which supplies water to the park. The water is obtained from the lower end of the passage, where it is said to be always present.

Running north from the main room is a small passage 30 feet long and averaging two feet in height. It is nowhere more than five feet

wide and leads very slightly upward. To the south a low broad crevice extends about 100 feet. In places this is only a foot high, two and one-half feet being the maximum. This passage is inclined, water being encountered at the lower end.

The drainage of the region is underground, and this cave receives its share. The water collects in the lower portion of the cave, where the water table is visible. But little drips from the roof and hence the cave is not very wet.

The roof is not covered in more than half the area by travertine deposits. These range in thickness from a thin coating to an inch or more. A few small stalactites are present, the usual size being a quarter of an inch in diameter and about two inches long. Still fewer stalagmites exist, these being larger than the stalactites. On the whole, the floor is bedrock, or bedrock covered by loose pieces of stone fallen from the roof. In no place was the floor muddy.

The floor and roof are exact casts of one another. As elaborated elsewhere in the general discussion of caves of this group, the floor and roof must at one time have been in contact.

The cave is visited by hundreds during the summer season, and a charge of ten cents for admission is made. The father of the owner, Mr. Martin, one of the pioneers of the region, is in charge of the cave, which is lighted by electricity.

BREWERY CAVE.

Brewery Cave is the other one in Crystal Rock Park. Its entrance is to the south of that to Crystal Rock Cave. Water from this cave was formerly pumped six miles to the Crystal Rock Brewery in West Sandusky, it being claimed that the water imparted superior qualities to the beer. However, before the Eighteenth Amendment closed the plant, it had discontinued the use of Crystal Rock water.

A brick-walled excavation, 21 feet in depth, and 14 by 10 feet, served as an entrance to the cave, and to house the pump and engines used to force the water to Sandusky. From the entrance an eight-inch pipe leads to the water, popularly called an underground lake. The pipe remains but the pumps and engines have been removed.

At the bottom of the entrance a passageway about two feet high leads into the main cave, which is divided into two parts by a large block of stone which dropped from the roof. The cave is nowhere more than four feet in height and tapers at the sides.

The cave dips northeast at a slight angle. Water is present at the lower end. A little water drips from the roof, and the floor is therefore damp.

There are no deposits in this cave, the roof consisting of bedrock and the floor being covered in most places by pieces fallen from above. These are angular blocks of varying sizes, one as noted above being sufficient to almost close one end of the cave. The floor is almost flat, and is covered with loose rock. The floor and roof at one time appear to have been together. This again is a cave of the type in which the floor was depressed or the roof elevated.

Good's Cave.

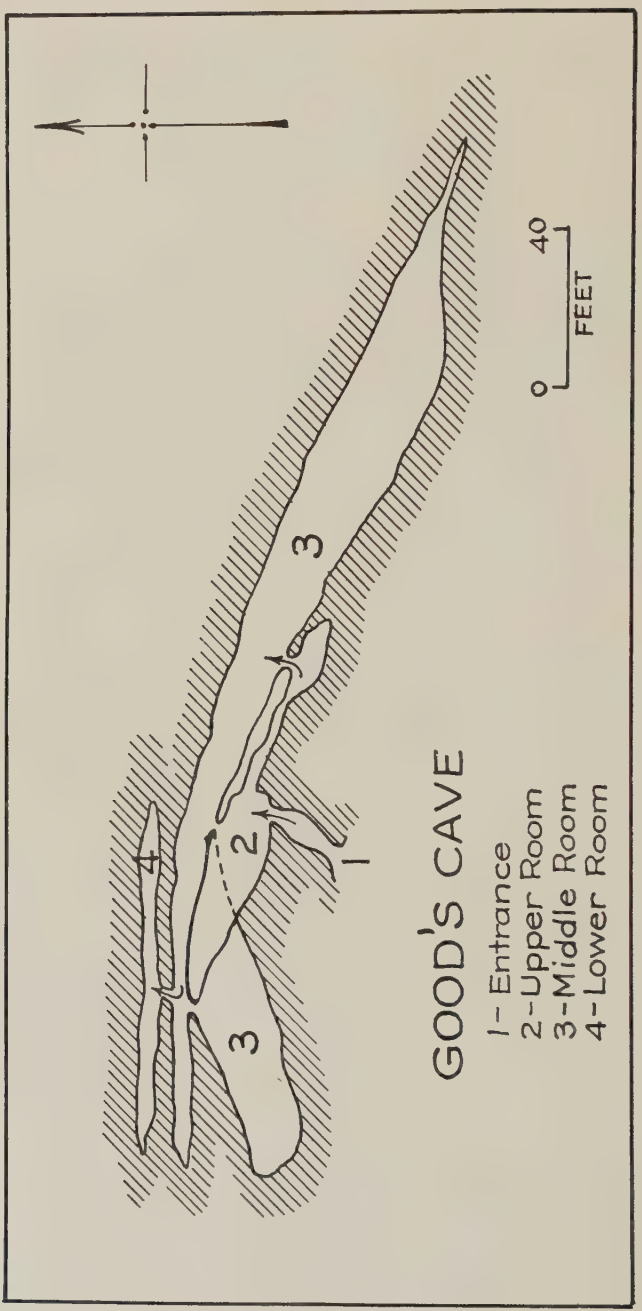
Good's Cave is in the northwest corner of Section 14, Thompson Township, Seneca County. It is about a mile southwest of the village of Flatrock, and four miles south of Bellevue, on the farm of Emanuel Good. The bedrock is crystalline, thick-bedded Columbus limestone. This cave is the third largest known in Ohio, and in addition, is the only one with three distinct levels.

The Entrance. The entrance is about 30 feet south of the public road running east and west along the north side of Section 14. It is not from a distinct sink hole, but rather from a fissure which intersects the surface. The cave is not the usual solution type, neither is it quite of the Put-in-Bay or Crystal Rock variety. The drainage of the whole region is mostly underground, the bedrock being fissured and shattered, and this cave seems to be simply a larger fissure. The surrounding country is a very gently rolling, almost flat, glacial plain, which has, as is usual in regions of young topography, rather poor natural drainage. The fields which are cultivated are tiled, the drains running to the lowest places where the fissured bedrock takes care of the water. Mr. Good, owner of the cave, states that even in prolonged wet seasons this means of drainage is very efficient.

The crevice at the entrance is only large enough to admit a man, being five feet wide and three feet high; it dips 55 degrees, north 15 degrees west, and has a strike north 75 degrees east. This narrow passage extends 50 feet downward, where it enlarges into a chamber called the Upper Room.

The Upper Room. This is 12 feet wide, 8 feet high, and 105 feet long, the length being in a general east-west direction. The floor of the Upper Room is not level, but dips in the same general direction as the fissure. The floor is covered near the entrance with clay washed in from the opening, the deposit resembling a small alluvial cone. This is clearly not residual, because such deposits are found nowhere else in the cave, and the course of the mud can be traced from the entrance into this room. Throughout the remainder of the room the floor is more or less covered with blocks fallen from the roof. Because of the clay and broken stone on the floor, it is not possible to prove that the floor and roof were at one time in contact, but such must have been the case because indisputable evidence exists in other rooms and passages, which will be described later. No deposits from percolating ground water exist in the Upper Room, the bedrock being fresh looking and unweathered. The same condition prevails throughout the whole cavern.

The Middle Room. From the Upper Room several passages lead to the room below but only one is large enough to permit of entrance. This is 10 feet wide and leads down 25 feet vertically, mostly over broken rock. At one time the passage between the Upper Room and the one below was continuous along the north side, but blocks of rock have fallen from the sides and roof into the narrow rift, choking it so that entrance to the room is possible only at this place. The second chamber, called the Middle Room, is the largest, being 225 feet in length, 20 feet in width, and having an average height of eight feet. This chamber extends almost north and south in a straight line, but


GOOD'S CAVE
1- Entrance
2-Upper Room
3-Middle Room
4-Lower Room
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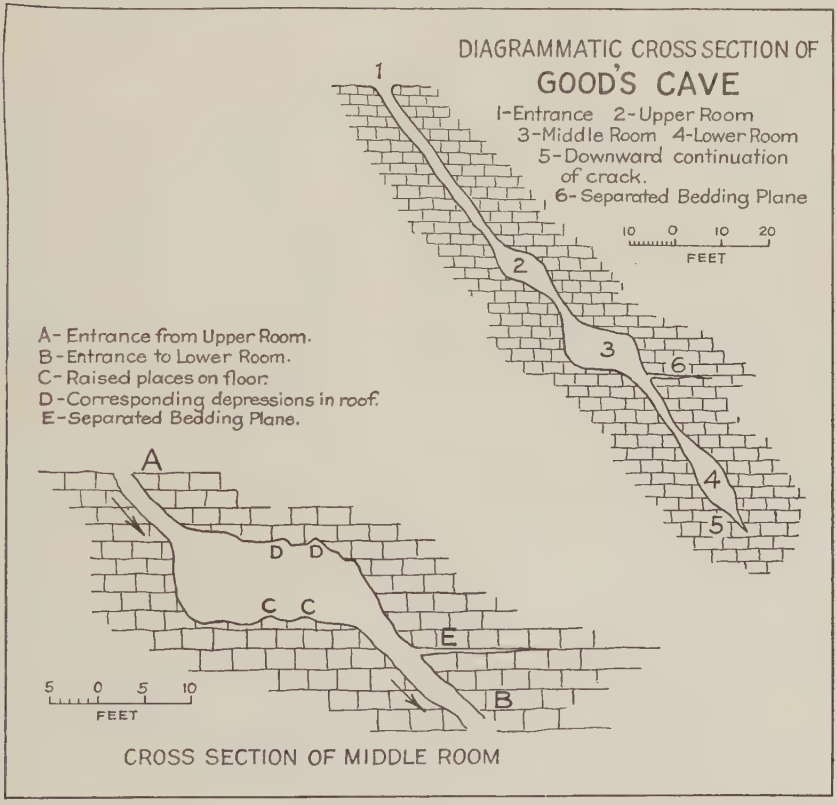
divides 60 feet from the west end. The most southerly of these is the larger, as shown on the map. The floor and roof are irregular and jagged although they are rather level, except at the extreme east end, where the whole chamber rises slightly. The irregularities of the floor fit those of the roof, that is, a depression in the roof has a corresponding elevation on the floor immediately below. Some loose blocks on the floor have fallen from above, but otherwise the floor and roof are bare. Two small



stalactites, the size and shape of a cigarette, are present near the entrance to the lower room but these are the only travertine deposits in the entire cave.

The Lower Room. The fissure which continues downward 40 feet at the usual dip of 55 degrees is so choked by pieces of rock from the walls that entrance from the Middle Room to the lowest can be made only at one place. About five feet below the floor of the middle room, along the north wall of the fissure is an opening which measures 15 inches at the fissure, but gradually decreases 30 feet northward where the beds again come together. The cross sections shown illustrate this. The bedding plane along which the opening occurs is evident on the

south wall, immediately across the fissure, but separation has not taken place there, proving that no movement or faulting has occurred. Throughout most of the forty feet that the fissure continues downward the walls are about six feet apart. Forty feet from the floor of the Middle Room, a vertical distance of 34 feet, the crack enlarges somewhat, forming a small room, 75 feet long, and varying from only one or two feet to several feet wider than the opening above. This is called the Lower Room. The cavity continues downward below the floor of the Lower Room, but is much narrower and so choked by fallen rock that further progress is impossible.

Various Features. When visited the cave was dry, but Mr. Good states that in rainy seasons water stands in the Lower Room, and in very wet weather in the Middle Room. He says that twice within his knowledge the water has risen to within a few feet of the entrance but has very quickly receded from this high mark. The water must flow in through cracks rather than from the entrance because the level rises quickly and falls quickly. The clay that is present in the passage from the entrance to the Upper Room seems to have been a gradual accumulation, rather than having been washed in by water. If the water partially filling the cave in wet weather came in through the entrance, clay would be more widely distributed through it. The only travertine deposits are the two small stalactites mentioned in the description of the Middle Room, so it would seem that the amount of water seeping into the cave through the limestone is negligible. That flowing into the cave must sink to deeper levels, and it may appear at the surface in the Blue Hole at Castalia, fifteen miles to the north.

This cave was not formed by solution, but by the separation of the walls of a fissure which might have been an irregular joint-plane. There can be no doubt that the walls were at one time in contact, because bedding planes can be traced from one wall to the other, and the raised places in one wall fit into corresponding depressions in the other. No faulting has taken place for bedding planes can be matched exactly at the same level from wall to wall.

Although this is one of the larger caves of the State, it is not regularly open to the public. It is away from the main line of travel and has no trees near by which would bring people to the locality for outings or for picnics. On account of the rooms on three different levels, and the cleanliness and dryness of the cavern, it may be profitably exploited in the future. The present owner has no objections to persons visiting it, and several "explore" it every season.

Underground River Cave.

Underground River Cave is in the northern part of Ridge Township, northwestern Wyandot County. It is three miles northwest of Carey, on the Carey-Fostoria road. This cave is mentioned by Winchell,[1] but a complete description is not given. It is owned and operated by Mr. M. L. Kelly.

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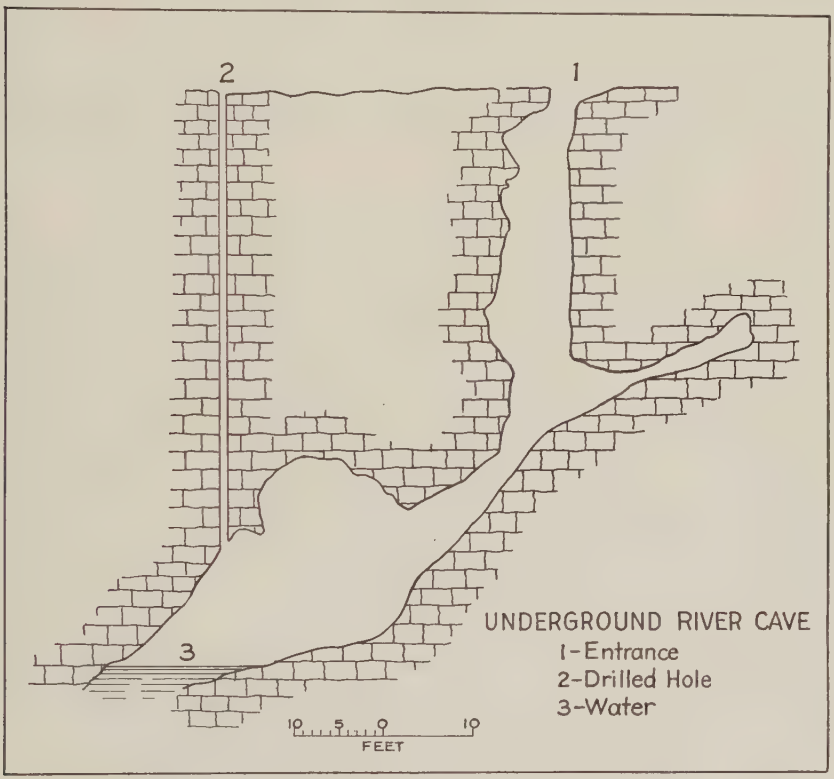
[1]Winchell, N. H., Report on Wyandot County, Geological Survey of Ohio, Vol. I, p. 631. 1873.

The entrance is from a summit of a ridge[1] which rises from 40 to 50 feet above the surrounding country. The bedrock is massive Niagara dolomite of Silurian age. It contains some gypsum. This cave is not the usual type with passages and rooms, but is a joint which has been enlarged. This has a dip of 70 degrees, north 55 degrees east and a strike north 35 degrees west. The vertical distance to the water in the bottom of the cave varies from 56 feet in April and May to 96 feet when the water is lowest in December and January. The width varies from



four to ten feet, and the length from eight to 20 feet, varying with the depth as illustrated by the cross section shown.

No ground water drains into the cave, but the surface of the water in it fluctuates as much as 31 feet. When visited it was 65 feet from the exterior surface, but during the winter it is reported to fall at least 20 feet below this. Many stories exist as to the depth of the water. The owner states that when it reaches the lowest mark there is a current which flows eight to ten miles an hour. It is popularly supposed that this stream comes to the surface in the Blue Hole at Castalia, 44 miles distant, but this seems improbable. The drainage of much of this part

[1]Idem, p. 627.

of the State is underground, the bedrock being more or less extensively fissured throughout the region. Most of the fissures are too small to admit of entrance, however, and those which are large enough have been covered or filled by farmers because of the menace to livestock.

No deposits are present in the River Cave. One cannot speak of this cave having roof and floor, but rather only two walls, which are of rock, and the clay which fills the joint at either end. Some slight movement seems to have occurred with the walls, and to some extent the material between them may be fault breccia.

This cave is lighted by electricity and plank steps lead to the water. A commodious rest house stands over the entrance. A hole has been drilled from the surface of the ground to the water in the cave which serves for ventilation and is occasionally used to mystify visitors by having someone talk from the surface to tourists below. A fee of 40 cents is charged for admission.

Zane's Cavern.

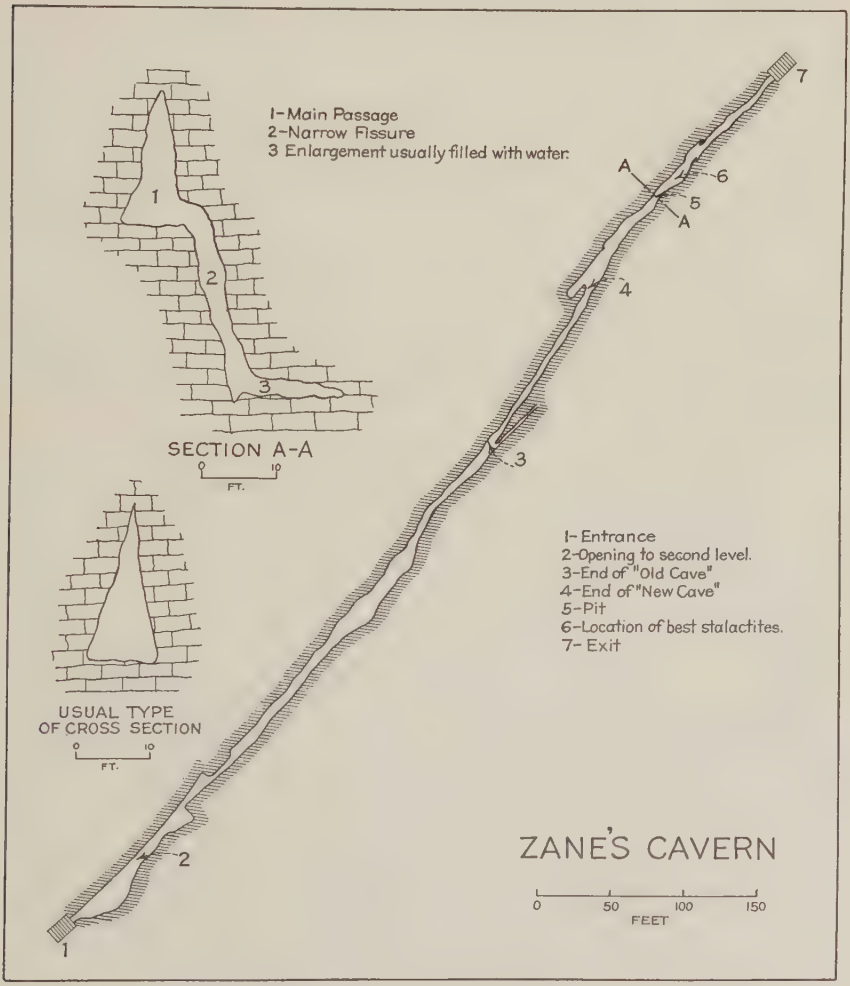
Zane's Cavern is in the northeast part of Jefferson Township, Logan County, six and one-half miles east of Bellefontaine, and three and one-half northeast of the village of Zanesfield. The cave is in the park and picnic grounds owned and operated by C. M. Richey and Sons. The bedrock is the massive crystalline Columbus limestone which outcrops in a band around the Bellefontaine outlier, on the eastern slope of which is found Zane's Cavern. At Campbell's Hill, west of the cave, on this outlier is the highest ground in the State, 1,550 feet above sea level.

The cavern extends from one side of a spur to the other in an approximately straight line, northeast and southwest, for a distance of about 800 feet. Each entrance is artificial, the original opening by which the cave was found having been covered. Until the winter of 1924–25 this cavern was really two separate ones, because for about 125 feet the passage between the two ends was little more than a crack. At that time it was enlarged so that communication between the two is now possible, and the two caves have been made into one. The two ends of the cave present different aspects because the older portion, which has been known for more than 20 years, has been robbed of all the stalactites, while the newer has all the stalactites and other crystals intact.

The "Old Cave."

The opening to the southwest, which is the entrance to the "Old Cave," has been excavated 25 feet to reach its floor. A flight of concrete steps leads from the surface to the bottom. The width at the entrance is four feet but this rapidly enlarges to 20, about 35 feet from the opening. Fifty feet into the cave is a depression in the floor which is 35 feet deep and crossed by a bridge 10 feet long. From this bridge the cavern continues with a width of from eight to twelve feet for about 250 feet where a second and smaller bridge crosses a depression which was filled with water when the cave was visited. From here the passage continues 125 feet to the end of the "Old Cave." The height of the cavern in most places is from 8 to 15 feet, but at one or two points it is as much as 20 feet.

At the terminus of the "Old Cave" the passage divides; the more southerly one is very small and narrow, and after about 40 feet becomes too small for passage. Formerly the opening to the north was also very small, but this has been enlarged for a distance of 125 feet to a width of from two to three feet, and a height of from five to seven to where it meets the former terminus of the "New Cave."



THE "NEW CAVE."

The "New Cave" presents a different appearance in the character of the deposits from the remainder of the cavern. The height varies from 8 to 14 feet, and the width from 4 to 20. About 150 feet from the entrance the joint crack continues downward 25 feet. This was filled

with water when the cave was visited, and it is the belief of the owners, based on previous explorations when the level of the water was lower, that it leads to a passage which may prove to be another room below. This will be opened to tourists if some means of drainage can be found to remove the water. A cross section of this is shown. The northeast entrance is also artificial, leading from the surface down 25 feet to the floor of the cavern by a flight of concrete steps.

Drainage. No water flows directly into Zane's Cavern, but it seeps in continuously, especially along the joint in the roof, and finds its way to lower levels. About 75 feet from the southwest entrance is a depression 35 feet below the floor of the main cavern. When visited this was almost full of water, but Mr. Richey states that in summer the water is lower, and that a passage runs an unknown distance from the bottom of this opening at right angles to the main cavern above. A stairway is being built to the bottom of this pit, so that in summer people may visit it when the water level drops. If the water recedes sufficiently parties may be taken into the passages.

At most seasons of the year water stands in the pit just mentioned, and in the depression under the second bridge referred to in the description of the "Old Cave." Water is also usually present in the hole 150 feet from the northeast entrance. It is apparent that the water in these lower levels is not all due to dripping from the roof, but must be part of the ground water of the region. For this reason the problem of drainage will be a difficult one.

Nature of the Floor and Roof Deposits. The floor of Zane's Cavern which is gently undulating is at the horizon of a very prominent bedding plane which can be traced throughout the entire cavern. The surface is rather smooth, except for blocks fallen from the roof or from the walls. While not muddy the floor is damp in places, and gravel has been spread over it. This obscures the original state of the floor.

The roof in most places is very narrow, because of the inverted V-shape of the cross section of the cavern. It is covered with travertine nearly everywhere. In the older portion of the cave all of the stalactites and the smaller stalagmites have long since been carried away. Through most of the cavern the walls are covered with travertine, which ranges in color from white to deep red.

In the "New Cave" the stalactites are numerous and intact, and great care is being taken to protect them. The dripping water has formed stalagmites on the floor and in some cases stalactites and stalagmites have grown together to form small columns. Some of the stalactites are 18 inches long, and two or three inches in diameter but the usual length is not more than a foot. Some are shaped like fish-hooks, while others have grown from the roof at an angle, instead of straight downward. This is probably due to irregular crystallization over parts of the stalactite.

Origin. The origin of Zane's Cavern has been by solution along the joint whose upward extension is visible at some places in the roof. Occasionally this is filled with gravel and other foreign material which has been washed in from above. The cavern has not been made by running waters, for at no place was a current observed. Part of the enlarge-

ment has no doubt been due to falling of blocks from the roof and sides of the cave.

Historical and General. The old portion of the cavern was discovered in 1893 by Lawrence Dunlap while hunting. The original entrance was where a small stream had cut through the roof of the cavern. This opening when enlarged was known as Unagsts Cave, and was sometimes visited. In 1922 two school boys found the opening to the "New Cave" at the opposite side of the hill. This had been an entrance to a den used by wild animals, and through curiosity the lads enlarged the opening and crawled into the cave. Mr. Richey was the next to enter this part but it was not opened to the public until an entrance was made, with concrete steps and with a strong door at the bottom where the passage leads into the cavern, so that measures could be taken to protect the unusually fine stalactites and stalagmites. The cavern was opened to the public on May 30, 1924, and that season parties were taken into the "New Cave" and then brought out and taken into the "Old Cave." The name of "Zane's Cavern" was given on account of the association with this region of the Zanes, famous in early Ohio history.

In the winter of 1924–25 the narrow passage that could not be traversed between the two caves was enlarged sufficiently so that now, 1925, parties will be taken in at one entrance and out at the other. This connecting of the two caves makes "Zane's Cavern" the second largest in the State.

The cave is electrically lighted and courteous guides are provided by the owners. Walks and bridges have been constructed so that a trip through it does not necessitate the wearing of old clothes and shoes. The beautiful park-like grove in which the entrance to the cavern is situated adds to the pleasure of the trip. Admission to the grounds is free, but a fee of 85 cents is charged for making the trip through the cavern.

Ohio Caverns.[1]

The Ohio Caverns, which are the largest known in the State, are in the northeast part of Salem Township, Champaign County, four miles east of the village of West Liberty, in an elevation locally known as Mt. Tabor. It is in the park and picnic grounds now owned and operated by A. H. Smith and brother. "Mt. Tabor is an elevation 1,278 feet above sea level along the eastern side of the Mad River Valley," and is an outlier of Columbus limestone capped by Ohio shale, to the southwest of the main portion of the Bellefontaine outlier. The cave is near the top of the Columbus limestone and at one place, near the present entrance, the overlying Ohio shale can be seen where it forms the roof.

The cavern "is approximately 1,800 feet long. Its general form is that of the letter Y, the (old) entrance being at the base of the letter, and the fork 1,100 feet from it. The passages run in a northeast direction up to the fork, where one continues along the same line and the other branches off to the north. The width of the accessible galleries varies considerably, the maximum being about fifty feet. Where this

[1]Part of the descriptive matter has been taken from Hills, T. M., "Reames Cave." Ohio Jour. Science, Vol. XVI, No. 6, 1916.

wide the height of all but a small passage may be reduced from a maximum of twenty-five feet to three feet or less. The wider places are usually the intersection of two joint-planes. This is not true of the northern arm, as its rooms are the largest in the cave and occur along a single joint-plane."

The present entrance which is near the fork of the letter "Y," is artificial and was made after Professor Hills' account was written. It is near the top of the hill, and descends 30 feet from the surface to the floor of the cavern. The descent is made from inside a building erected over the opening to house the plant furnishing electricity for the cave, for an office, and for a waiting room for tourists. Parties are taken into the northern arm of the "Y," then back through the base of the letter, and out at the end. A third opening exists at the end of the northern branch, but this is not used at present (1925).

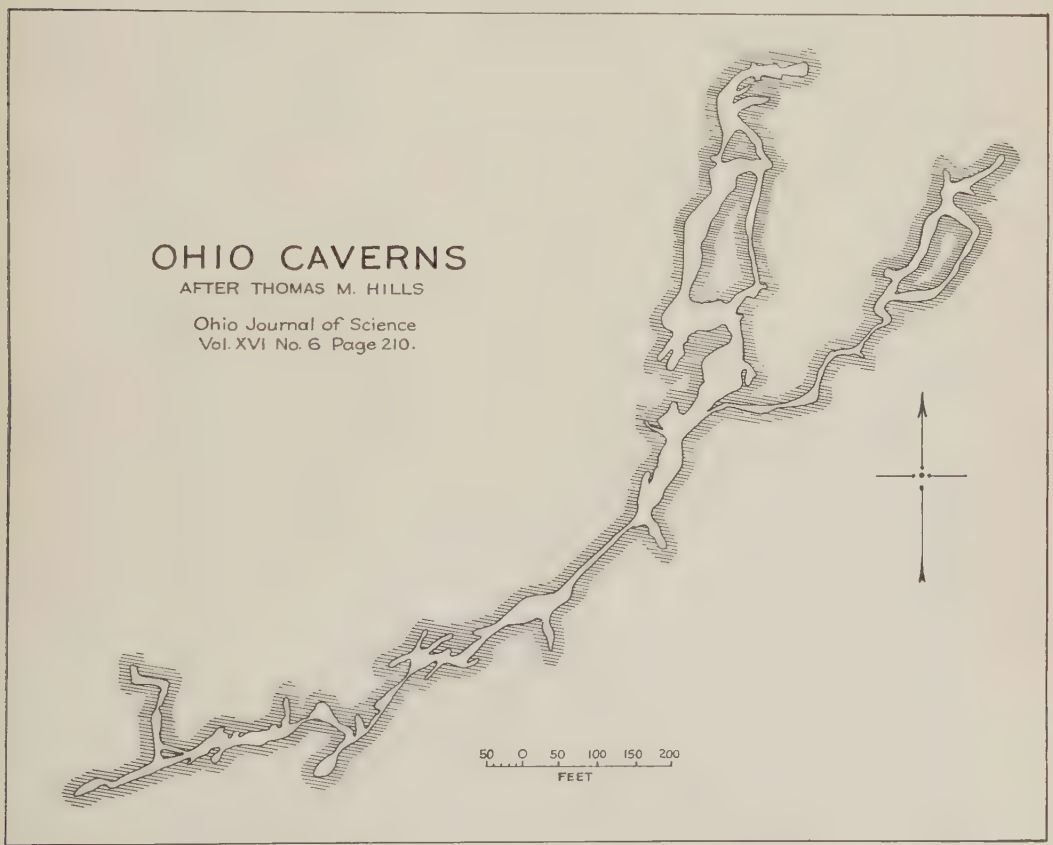
"The rooms are small and narrow near the entrance (at the base of the letter 'Y') but increase in size near the inner end. They follow a northeast-southwest joint-plane which can be seen along the roof. Solution has widened the joint-plane along layers that are decidedly saccharoidal in texture. This expanded area is usually near the roof of the Cave." The resulting cross section is usually V-shaped, that is, the width at the roof is greater than at the floor. The usual height is about eight feet, but in a few places may reach a maximum of 25 feet. "At certain places solution along bedding planes far surpasses that in the other directions, and larger rooms are * * * produced."

"At the extreme end of both branches the floor of the cave is quite muddy, due to the constant dripping from the roof, at least in part. This is due to the fact that the cave in its northwesterly course passes beyond the limit of Mt. Tabor hill, and is partly under the valley to the east of it. While the surface drainage into this valley from Mt. Tabor carries off most of the water, enough descends through the mantle rock to give an abundant supply for solution and deposition in the cave."

The floor and roof are usually level, and except in some of the larger rooms, caused by solution along prominent bedding planes, are rather smooth. In these rooms many blocks have fallen from the roof, some of which are very large. One is called the "Giant's Coffin" on account of its size and shape. A walk, of concrete in most places, has been constructed throughout much of the cavern, incidental rough places have been smoothed over, and pieces of rock removed from the pathway, thus obscuring the original state of the floor in most of the cave. The northeast end of the cavern is 35 feet lower than the southwest end, but the slope is so gentle that ordinarily it is not noticed. No pronounced changes in slope are present and no real indications of any levels below the single known one are to be found.

The deposits of the cave are many and varied. "The smaller stalactites are simple in form. Hundreds of them, about the size of a cigarette, are hollow, thin-walled tubes, that hang from the roof in the wider part of the cave. They are still covered and filled with water, and probably started their growth at a not distant past. The larger ones are from three to five feet long." Since the foregoing was written (1916) many of the best stalactites were removed from the main passages, indeed, most

of the cavern is quite bare of deposits except those of sheet-like character. However, in some of the side passages, especially those of the northern branch, are many fine stalactites and stalagmites. The size ranges from an inch or two in length to a foot, but a few are larger. The present owners are endeavoring to protect the remaining deposits. In many places travertine lines the walls in sheets, which are often several inches in thickness. The color ranges from the purest white to very dark red, with all the variations between the two.



"The concretions in the saccharoidal layers stand out prominently along the upper part of the walls of the cave. They vary from a few inches to several feet in diameter." These are of chert, and appear without exception to be broken across. Suggestive names have been given some of the larger concretions exposed in the walls, such as the "Beef Heart," and the "Ham."

The cavern was discovered in August, 1897, when ground at the southwest end of the cave sank. That part of the land in which this entrance was located was owned by a Mr. Reames, and the cave was

usually known as "Mt. Tabor Cave," from its location, but the owner much preferred to have it known as "Reames' Cave," and so it was described by Professor Hills. Much of the cavern, however, was under land owned by other parties, although they had no way of entering it except through the Reames' opening. Later an entrance was made at the northeast end of the "Y," and parties were taken in from there. This led to friction, but finally the present owners, A. H. Smith and brother, bought the Reames' interest, and now the cavern is run as a unit under the name of the "Ohio Caverns."

An admission charge of ninety cents is made for entrance to the Ohio Caverns. The parties taken through usually contain from ten to twenty people, with a guide at the front of the column who describes the various features of the cave, and a guide at the rear to prevent straggling, and also to protect the stalactites. A little more than an hour is required for the trip.

Lawrence Cave.

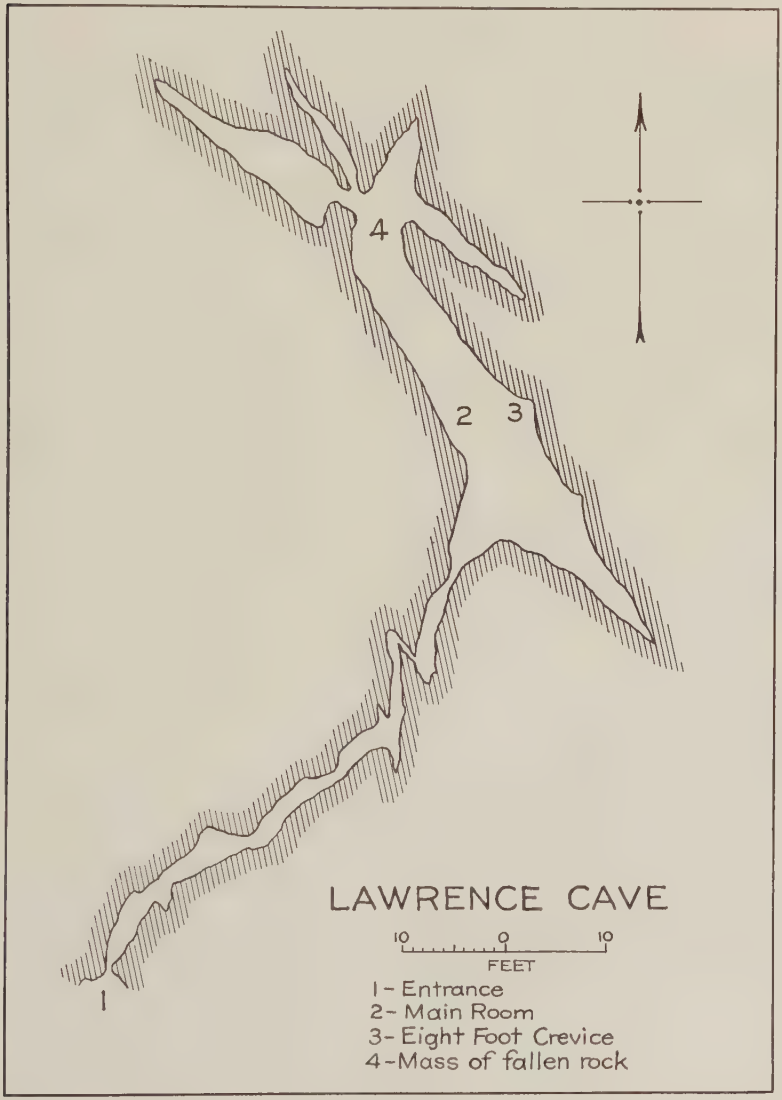
Lawrence Cave is on the Lawrence farm about one-half mile west of the Olentangy River and two and one-half miles north of Powell, Liberty Township, Delaware County. It is in the Delaware limestone, of Devonian age, which in this locality seems to be more massive and thick-bedded than is usual. On account of the clay and fallen rock in the lowest part of the cave it is not possible to tell with certainty if the cave extends through the Delaware and into the Columbus limestone.

The entrance is from one of the many sinks which are common in the region, the drainage being mostly underground. The top of the funnel-shaped opening is 30 feet in diameter and 30 feet deep. From the bottom of this a narrow crevice, which marks the beginning of the cave, leads down six feet farther to a tortuous passage which has a general northeast direction, is about 75 feet long, and which leads into the main room. This passage, which slopes gently downward, is from two to five feet wide and from six to 15 feet high.

The main room has its greatest dimension northwest and southeast. It is about 50 feet long, 12 feet wide at the greatest, and has a height of 25 feet. Directly opposite the entering passage is a crevice in the floor which is eight feet in depth, but which is too small to allow entrance. The height and width of the room decreases toward the southeast. At the northwest end a great fall of rock from the roof has almost filled the cave, so that further progress is very difficult. This point is indicated on the map. From here the cave extends about 20 feet farther in a northwest direction.

When visited the cave was muddy, but no water was present. However, in rainy weather water is said to fill the lower part. The water which finds its way in must work its way through the fissured bedrock to the Olentangy, which drains the region. The floor is covered with mud and with pieces of rock fallen from above. The roof is flat in most places, caused by a prominent bedding plane. A few small stalactites are present, but these have a muddy appearance. The floor and parts of the walls are covered with clay, some residual, and some washed in, especially in the northwest part.

The cave has been formed by solution along joints, that in a northwest-southeast direction forming the main room, and that along a less well defined series with a general northeast-southwest direction forming



the passage from the bottom of the sink to the main room. It is probable that additional caves exist in the region, but all of the other sink holes examined are filled at the bottom with debris, concealing any possible entrances.

Nothing is known of the discovery of the cave, and no improvements have been made, such as stairs and electric lights. It is not visited, except by occasional students and others in search of the new and unusual. No objections are made by the owner to these visits.

Thompson's Cave.

Thompson's Cave, which is small and unimportant, is on land owned by Harry Thompson, one-half mile south of Covington, in the southern part of Newberry Township, Miami County. The bedrock is Cedarville dolomite of the Niagara Series. The entrance, which is along the east bank of Stillwater River and about 100 feet from the stream, is eight feet wide at the bottom, and eight feet high. It is an inverted "V," as is the cross section of any part of the cave. The height and width decrease rapidly from the entrance for about 10 feet, where the passage enlarges into a small room about 12 feet long, eight feet wide and eight feet high. Beyond this the cave continues 25 feet farther, the width and height gradually decreasing to the end.

The cave is dry and consequently no solution or deposition appears to be taking place. The floor, which is partially covered with small pieces of rock fallen from above, is rather smooth except for these fragments, while the roof is somewhat jagged, caused by the projection of points of rock. The solution responsible for the cave took place along a joint which, in most places, can be traced upward from the roof. The straightness of the cave is further proof of this type of solution.

Because of the small size this cave has no commercial possibilities. At one time the cavern was a little longer than it is now, but some of the limestone has been quarried from the entrance for use in a lime kiln which at one time was in operation near by.

Painter Creek Cave.

Painter Creek Cave is on land owned by Charles Senseman along the north side of Painter Creek, a mile west of its junction with Stillwater River, in Section 7 of Newton Township, Miami County. The bedrock is lower Niagara limestone.

The cave has two entrances, 35 feet apart, which meet and continue as a single passage. Both entrances are about 10 feet above the level of the stream and open from the bank which is vertical. The entrance to the east is arch-shaped, 10 feet wide and five feet high. The longer part of the cave seems to be a continuation of this entrance. The main passage is to the northwest for 35 feet, where after a right angle turn it continues to the northeast for 30 feet, or to the terminus of the cave. The width from the entrance to a place about 25 feet into the cave is 10 feet; there it abruptly narrows to three feet, but expands immediately into a small rudely circular room about eight feet in diameter. From this room the northeast passage continues 25 feet, gradually becoming slightly narrower, and then expands into another small room about eight feet wide, which forms the end of the cave. The height decreases from five feet at the entrance to two feet at the first constriction; it is four feet in the first small room and decreases to three in the smaller terminal chamber.

The entrance to the west is 10 feet wide and six feet high and is also arch-shaped. The passage from this is east for 24 feet, where it meets

the main cave 16 feet from the east entrance. The height gradually decreases from six feet to five. At the junction of the two entering passages a very small opening extends directly south to the bank of the stream. This is only about six inches in diameter and is straight enough for light to pass through it.

The cave is dry, and no further enlargement appears to be taking place. In flood time water is said to enter the two entrances. The creek at this place flows between rock walls, so a rise of ten feet must occur frequently. The cave of course, on account of its small size, has no commercial possibilities.

Miami River Cave.

The Miami River Cave is near the boundary between Section 11 and Section 14 of Clinton Township, Shelby County, on the west bank of Miami River. It is four miles south of Shelby, and eight miles north of Piqua. The bedrock is Niagara in age.

The entrance is from the rock wall that borders the stream, and is only about three feet above the water level. The entrance is five feet wide and six feet high, and rather arch-shaped. The passage from the entrance is 15 feet to the northwest, where the height decreases to four feet, but the width remains about six; here the passage turns at right angles to the northeast and continues in a nearly straight course for about 25 feet. The width decreases to two feet and the height is still less at the end. From the terminus of this northeast passage, the cave continues 15 feet to the northwest, the width being three feet and the height two. The end of this is the terminus of the cave.

The floor is level, but is rather rough. It is covered by mud washed in by the river when swollen by floods. The walls and roof are covered with old travertine, but no deposition is going on. When visited, the last half of the cave was wet and quite muddy. It is probable that the water backs into it whenever the level of the river becomes much higher than normal.

This cave has been formed by solution, the sharp angles suggesting joints. The cave is small, difficult of access, and wet, and hence is not of even local importance.

Buckskin Caves.

Buckskin Caves is the name given to two small caves situated along the west bank of Buckskin Creek, about a mile and a half north of the village of Bainbridge, in the northern part of Paint Township, Ross County. A mile south of the caves, Buckskin Creek which flows south joins Paint Creek. The bedrock is the massive crystalline Greenfield dolomite of the Bass Island formation of the Monroe, which outcrops along the bed of the stream. It is overlain by Ohio shale, which forms the hills on either side of the creek.

The most southerly of the two caves has its entrance in the bank of the stream, four feet above water level. The entrance is six feet high and 10 feet wide. The main cave extends 32 feet west, where a small passage continues 25 feet to the south. The height decreases from six feet at the entrance to four feet midway into the cave, and contracts still farther toward the end. The entire cave rises three feet from the entrance to the terminus.

The cave is dry, but in wet seasons considerable water must flow into it for indications are present of a flow from it at times. The floor is covered with dried mud, which increases toward the inner end, showing that it is not wholly residual from the solution of the limestone, but in part at least, has been washed into the cave. The floor and roof are not markedly irregular. A thin veneering of travertine is present on the roof and walls in many places. The travertine has not been deposited in the form of stalactites and stalagmites, but rather in more or less thin sheets. During flood time the water enters the mouth of the cave.

The origin has been enlargement of joints by solution and the one along which this took place to form the main cave is plainly visible above the entrance. The Detroit, Toledo and Ironton Railroad runs parallel to the stream through a cut at this place, the track being above the caves. This cut has decreased the thickness of the roof from perhaps 40 feet to 20, and gives the heavy rains a better opportunity to flow into the caves. Further, the breaking of the natural slope of the hill by the cut arrests the flow to the stream and gives it more chance to percolate into the caves. Evidence that such action has been promoted in very recent times is present in the increased deposit of mud on the floor which is unlike the residual material usually found in caves.

The second cave of this group is about 100 feet north of the first, and has the same position in relation to the stream on the east and the railroad on the west. The entrance, which is four feet above the level of the creek, is 10 feet wide. The main cave is 25 feet long and from its end a smaller passage extends 40 feet at right angles. The cave rises three feet in the first 10 from the opening, but it is level for the remaining distance.

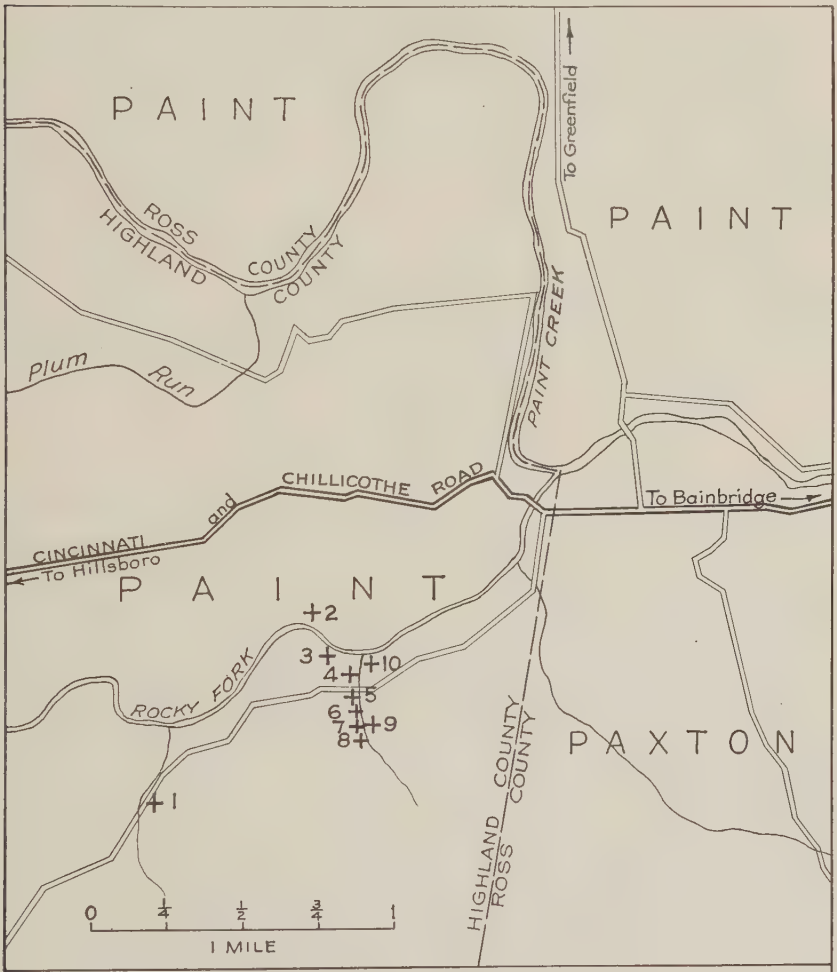
This cave, like the preceding, was dry when visited but shows the same sort of evidence of water flowing through it in wet weather. The walls and roof are covered with travertine which is much thicker and more abundant than in the one to the south. The travertine is also more weathered and in most places is overlain with a film of residual clay. The floor also is covered in the main with this material in addition to mud which has apparently been washed in. From the entrance of the main cave to the end the floor is covered with small limestone pebbles, some approaching the size of an egg. These have been partially cemented with travertine, producing a conglomerate similar in appearance to that formed in certain glacial deposits by calcareous cementation of drift, except that in the latter case the pebbles are of course made up, in part at least, of foreign material.

Buckskin Caves are seldom visited and no commercial exploitation has been attempted. Their small size and inaccessibility preclude their ever having much general interest.

Rocky Fork Caves.

Rocky Fork Caves, the largest group in Ohio, are in the southeastern part of Paint Township, Highland County, just north of the corner of Highland, Ross, and Pike counties, along Rocky Fork of Paint Creek. The region is a wild, wooded one, a mile by dirt road from the Cincinnati-Chillicothe Pike. The land in which the caves, with the exception

of Dry Cave, are located, is owned by a group of Chillicothe business men. Mr. C. A. Ellison is the caretaker. The bedrock is massive, crystalline Cedarville dolomite of the Niagara Series.



MAP OF ROCKY FORK REGION
SHOWING LOCATION OF
ROCKY FORK CAVES

1-Dry Cave
2-Ellison's Cave
3-Marble Cave
4-Crescent Cave
5-King's Wardrobe Cave
6-Wet Cave
7-Buzzard's Glory Cave
8-Dancing Cave
9-Bear Cave
10-Fox and Coon Cave

Entrance to these caves varies but a few feet in altitude. The accompanying map shows the location of the entrances, most of which are on a tributary to Rocky Fork, locally known as Cave Run. The remainder are on the banks of the larger creek, which flows east at this place. Rocky Fork here flows through a narrow gorge 75 feet deep, while Cave Run flows into it through a cleft of the same depth which at places is only five feet wide, but whose usual width is from 30 to 50 feet.

There is a tradition that Daniel Boone, and a contemporary, Andrew Ellison, were the first white men to see these caverns. Unlike many where the entrances are from sink holes, and thus hard to find, these are conspicuous because they open from the sides of a deep valley. It is probable that the Indians knew of the caves, and may have occasionally used them.

The caves of this group have not been much "improved," as have most of those in the State that are operated for profit. As they are not lighted by electricity, visitors must use candles or flashlights for illumination. On the whole, these caves, although most are rather small, offer the best opportunity in Ohio to see such natural phenomena in their original and unaltered state.

BEAR CAVE.

The entrance to Bear Cave, which is arch-shaped, is on the east side of Cave Run, 200 yards south of its junction with Rocky Fork. The height which at the entrance is ten feet, gradually decreases until 25 feet within it is but six feet high. The arch-like character is lost from this place, on account of the widening upward for three or four feet along the joint, which originally determined the location of the cave. A very small passage enters from the north, 60 feet from the main opening. It is also arch-shaped, three feet wide, and of the same height. As this smaller passage approaches the larger, the width decreases to eight inches, and the height increases to five feet, entering the main cavern six feet above its floor. Eighty feet from the mouth, the main entrance enlarges to form a roughly circular room, having an average height of three feet. This cavern has no noticeable dip in any direction.

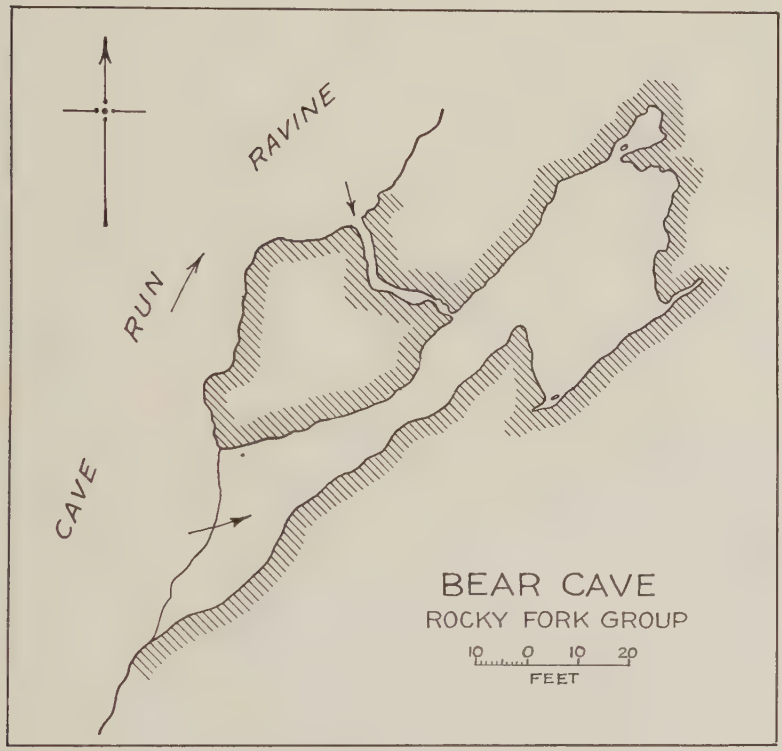
Since this cavern is dry, probably further enlargement is not taking place. The entire roof is covered with old porous travertine, and has the appearance of weathered bone, unlike the usual glossy surface of fresh travertine deposited in an active cave. The walls also a few feet back from the entrance are covered with similar material. All of the stalactites, of which only a few existed, have been broken off, except one or two small ones at the rear of the cave. As indicated on the map, one column, 18 inches high, and five inches in diameter, has been formed by the coalescence of a stalactite and a stalagmite. The floor is covered with residual clay and blocks of stone fallen from the roof. The largest of these is four feet square and three feet thick, but most are very much smaller.

The roof is irregular, the highest part being on the joint-plane along which the cave was formed. The height may reach 10 feet in this crack, with a width of only two feet, while the general height is only five feet or less. The floor is level except for the fallen blocks.

The cavern takes its name from its having been known to pioneers of the region as a bear den. It is warm and dry, and the entrance is easy of access so that of all the caves of this group it seems best suited for such a purpose.

FOX AND COON CAVE.

Fox and Coon Cave is a small one, the entrance to which is about 75 feet above Rocky Fork, and at the point where Cave Run flows into the



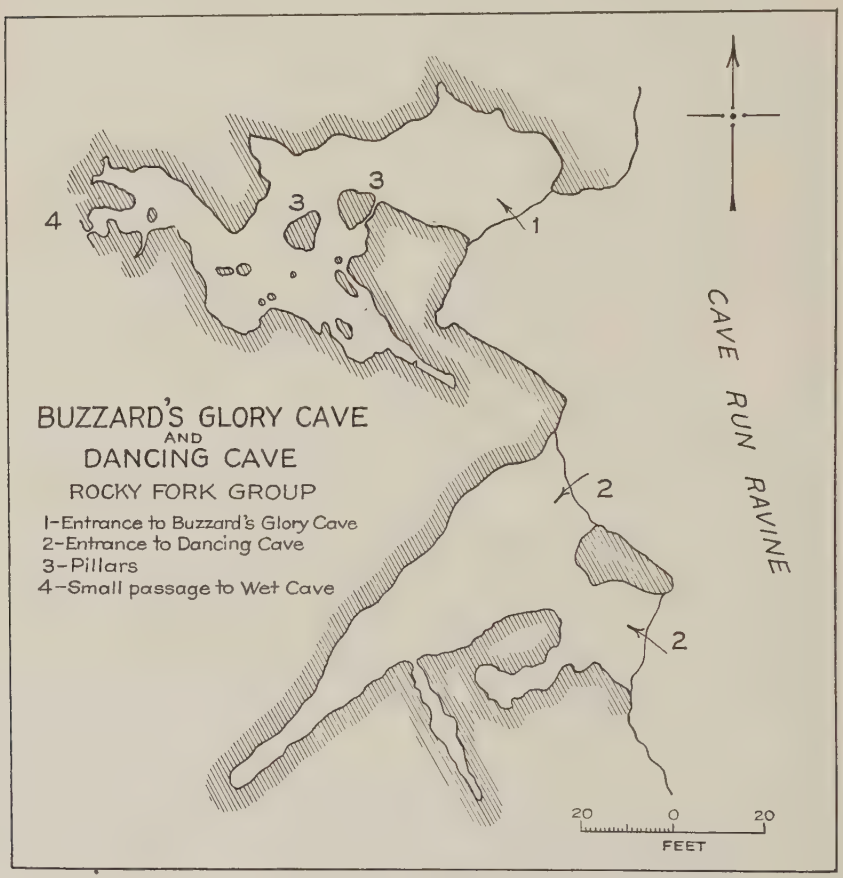
larger creek. It is only slightly more than 20 feet in length, and the greatest height is three feet. The general shape is that of a fish-hook, sloping upward 10 degrees from the entrance.

There are no deposits of consequence, the cave being dead, and no water was seen. The floor is smooth, and is covered with residual clay, which because of dryness is dust-like. This is the smallest and least important of the Rocky Fork caves. The name has been given because small animals have been known at times to make it their den.

DANCING CAVE.

Dancing Cave is the farthest to the south on the west side of Cave Run, almost across from Bear Cave. It has been formed by solution along a joint-plane, the lower portion having been enlarged more than

the upper, that is, the cave is wider at the floor. This is one of the most impressive of the group, on account of the imposing vaulted entrance, 15 feet high, with a smaller entrance to the east five feet in height, as shown on the map. The cavern extends 110 feet southwest, the width and height gradually decreasing and the floor rising 12 feet from the entrance to its terminus.



Very little action is now taking place so the travertine which covers roof and walls and which at places is a foot in thickness, is dry and lifeless in appearance. The floor is covered with residual clay, and with small pieces of rock fallen from the roof. No moisture was observed in it.

The small passage which extends to the southeast from the main cave has its opening three feet above the floor of the cavern. It is very small and has been formed by solution along intersecting joint-planes. The height of the cavern decreases gradually from 15 feet at its entrance to three feet at the end. The deposits on the walls and roof are also impressive, less so however because of their lifeless appearance. It is not known how the name was acquired.

BUZZARD GLORY CAVE.

Buzzard Glory Cave is 60 feet north of Dancing Cave, along the same side of Cave Run, but it is very dissimilar to that cave, being low, wide, and rather damp. Solvent action has taken place along a bedding plane, rather than along a joint. The roof is flat, and no upward extension is apparent along any fissure. The entrance is at the same elevation as that of Dancing Cave, but unlike that one. it is only five feet high and decreases rapidly in the cave. The average height back from the entrance is only 18 inches, and is even less at the extreme ends.

No water finds its way into the cave under normal conditions, but in very wet seasons some must flow into it. The floor is damp but not wet. In the farthest recesses there are a few small cigarette-shaped stalactites, which are hollow, but on which no deposition is now taking place. The walls are covered with residual clay, and with small pieces of rock fallen from the roof. The pillars shown on the map are, with one possible exception, of country rock, rather than the joining of stalactites and stalagmites, as is often found in caves.

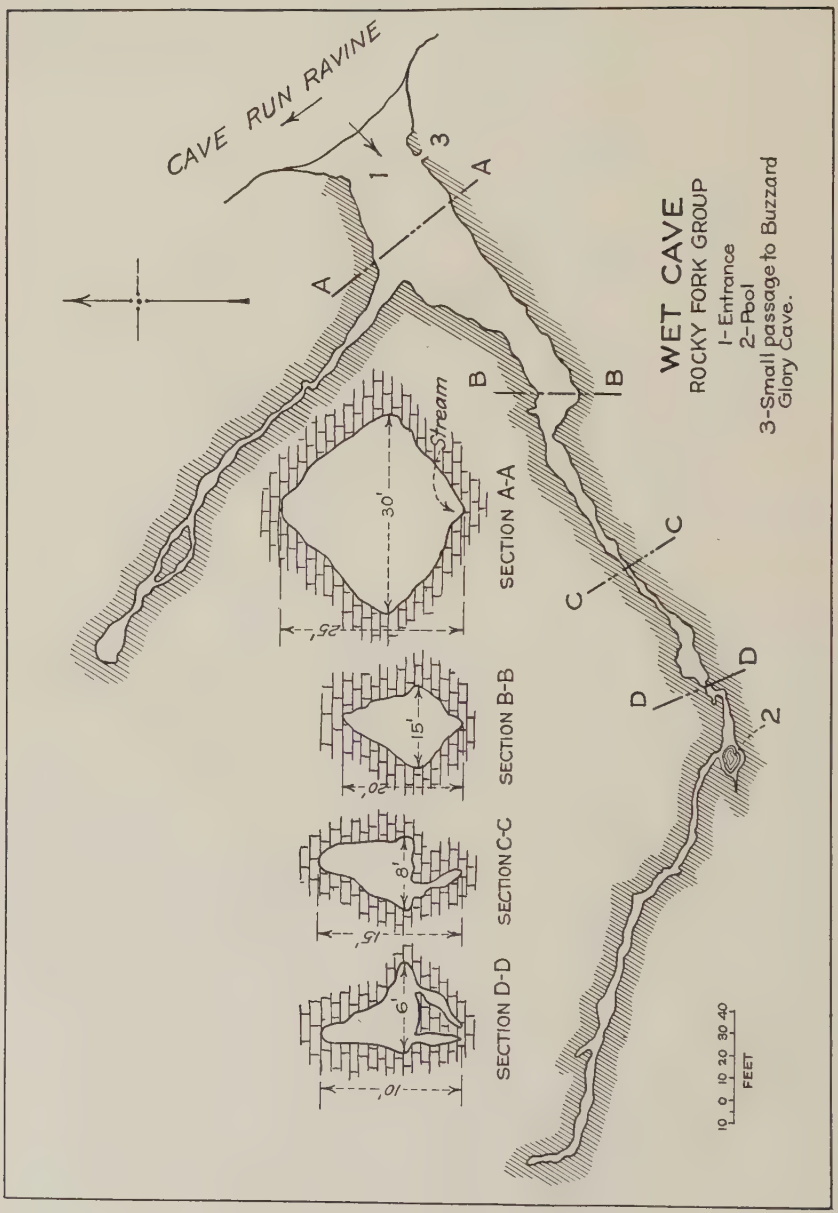
A very small passage, hardly more than a crack, a foot wide and less than six inches high, leads from the west end of this cave to Wet Cave, the next on the north. Such a passage is of course too small to admit the body of a man, although it is so narrow for only about a yard. Buzzards have been known to nest in this cave, hence the name.

WET CAVE.

Wet Cave is the largest, and the only one in the group in which active enlargement is now taking place. The entrance, which is 50 yards north of that of Buzzard Glory Cave, is 32 feet wide and 15 feet high. The floor dips from the entrance 15 feet in the first 40, but the main cavern is almost level for the remaining 275 feet. At the end of the main cavern is a small room, 18 feet wide, and 15 feet high. Five feet above the floor a small passage extends 210 feet to the northwest. Near the room it is two and a half feet high, but rapidly decreases so that in the last fifty feet the roof is only nine inches above the floor.

The main cavern varies in height from eight to 30 feet, and in width from five to 40. The passage which branches off to the northwest, 40 feet from the entrance, has an average height of six feet, but is less in width. At the end of this passage is a room 15 feet wide and 25 feet long. Much clay is present here and appears to have been washed in by ground water, rather than left as residual material from the solution of the limestone as is indicated by the texture and unequal distribution of the material.

A pool of water 12 feet long and eight feet wide, the bottom of which is reported to have never been found, occupies the center of the room at the end of the main cavern. However, the beams from a focusing flashlight seem to reveal the bottom, and the writer strongly suspects that 20 feet would be an adequate depth to assign. From this pool a small stream flows toward the entrance. Water drips from the roof in many places, but the most seems to find its way into the caverns near the vicinity of the pool. The two narrow passages have a small amount of water trickling from them, more coming from the one nearer the


CAVE RUN RAVINE
WET CAVE
ROCKY FORK GROUP
1- Entrance
2- Pool
3- Small passage to Buzzard Glory Cave.
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
Stream
30'
25'
15'
20'
8'
15'
6'
10'
10 0 10 20 30 40
FEET

entrance, the floor of which is very muddy. During rainy seasons the amount of water making its way into the cave is considerable, because there are several sink holes immediately above it, one of which is 30 feet across. The water does not flow out at the entrance through an open channel, but percolates through the floor into Cave Run, 60 feet below.

The deposits of this cave are not of the usual travertine type, but consist of soft, plastic residual clay, from the solution of the impure limestone. This clay covers the floor, walls, and roof, the greatest thickness being more than six inches. While this is the largest and most interesting of the group of caves in this section, the sticky clay makes it by far the dirtiest, so that its popularity is not in proportion to its size and interest. While there are no stalactites found in the cavern, there are many projections from the roof which resemble them in shape, but on close examination these prove to be country rock left in unusual shapes by their resistance to solution.

The floor of this cave is very irregular, especially in the main cavern, where the stream has cut a tortuous channel in the rock. This has a maximum depth of seven feet, but in only a very few places is it wide enough to admit the body of a man. It offers no serious bar, however, to progression into the cavern, for the roof is ten feet above the floor in most places. The map, with its cross sections through various parts of the main cavern, shows this narrow channel sunk below the floor. This irregularity as well as the muddiness of the floor is another contributing factor to the unpopularity of this cave.

The origin of this cavern has been solution along joints, and this action is still going on, but not to the extent it once did. It is the only cave in the group which is really active. While it is the one most visited in the group, people as a rule, go but a short distance because special shoes and clothing are necessary for a trip to the pool. The name, of course, has been derived from the water in the cave.

KING'S WARDROBE CAVE.

The entrance to King's Wardrobe Cave, which is 50 feet north of that of Wet Cave, is five feet high and 25 feet wide. The floor has the same elevation as the roof of Wet Cave. The cave narrows rapidly from the entrance and at a distance of about 50 feet divides into two small passages, each five feet wide. After 30 feet these reunite into a single passage which continues 65 feet farther, gradually becoming narrower and lower. The height where the cave divides is three feet, and from this point it rapidly diminishes to two, and in the last few feet is less than 12 inches.

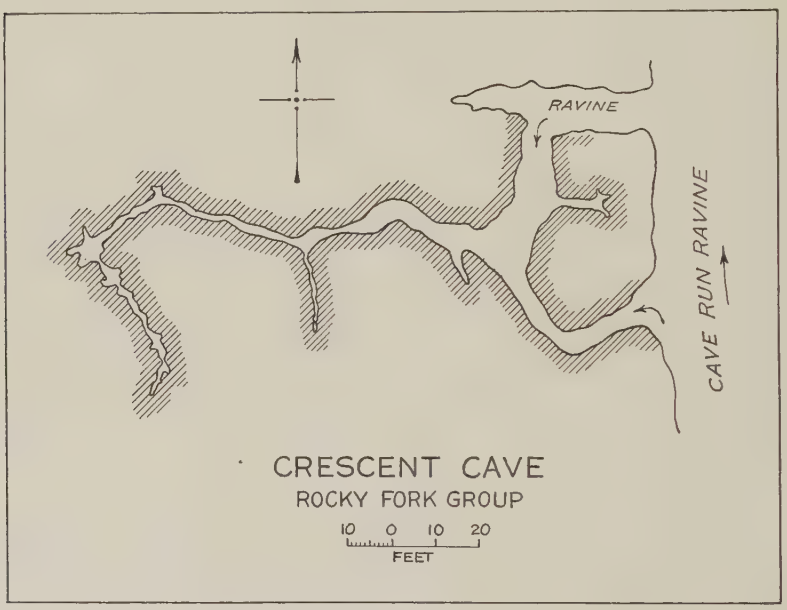
The cave apparently has no water running into it, and hence, although the floor is damp, it is not muddy. No fresh material is being deposited, but the walls and roofs are covered with old travertine. At one time a few small stalactites were present, but these have been broken off. Formerly near the entrance there was a mass of stalactites arranged in a circle three feet in diameter, having a fancied resemblance to an inverted crown. These have been destroyed, but the bases remain and still somewhat resemble a crown, hence the name. The floor and roof are essentially smooth and flat. The floor is covered with residual

clay, and with a few small pieces of rock, mostly travertine, which fell from the roof.

It is probable, as shown from the configuration of the cave, and from the right angle turns, as shown on the map, that the solution has been along joints, but any enlargement upward in cracks from the roof has been masked by the thick travertine deposit.

CRESCENT CAVE.

Crescent Cave is along the west side of the gorge of Cave Run, just south of its junction with Rocky Fork. At this place the rock walls are perpendicular, and a walk has been fastened to the cliff so that access



may be had to the larger entrance which is 10 feet high and five feet wide; the smaller one to the north is three feet high and six feet wide. An opening connects the two and midway between them is a very irregular passage which extends 100 feet to the west, and then turns south at a right angle for 50 feet. This north-south opening is very narrow, less than a foot wide at places, and very crooked, but the height averages six feet.

Very little water finds its way into the cave, and what does, drips slowly from the roof at the farthest end, where the floor is muddy. No water flows from the cave, in fact the floor near the entrance is dry. A very little solution seems to be going on at the end of the cave, but this activity does not extend beyond the right angle turn.

Travertine covers the walls and roof in most places. No stalactites remain, but the bases of many, most of which are about two inches in

cross section, bear out the statement of Mr. Ellison that when these caves were first opened to the public, stalactites were broken off and carried away by almost every visitor, some removing many. The roof is uneven, extending upward along a joint crack, on which the solution has taken place to form the cave. The roof is from six to seven feet above the floor almost to the end of the cave, where the height decreases slightly. The floor of the first half is fairly regular, and is covered with residual clay, but the floor of the remainder is very irregular, and in most places is covered with more or less clay.

In the period following the Civil War a notorious bandit, McKimmey by name, terrorized the countryside in this vicinity. He used this cave as a hiding place when hard pressed, and as at that time the larger entrance was inaccessible, this stronghold was easily defended, and was dry and habitable. Hence this is sometimes called "McKimmey's Cave."

MARBLE CAVE.

The entrance to Marble Cave is from a small tributary on the south side of Rocky Fork, about 100 yards west of its junction with Cave Run. The entrance has been enlarged upward along a fissure for a short distance and the height, aside from that caused by the joint, is five feet. This is rather uniform through most of the cave.

The floor, walls, and roof are covered to a depth of several inches with old travertine. None is being deposited at present, consequently it looks very much weathered. Stalactites at one time were quite abundant, judging by the bases present, but not one remains. The floor and roof are fairly regular, no dip in any direction being noticed.

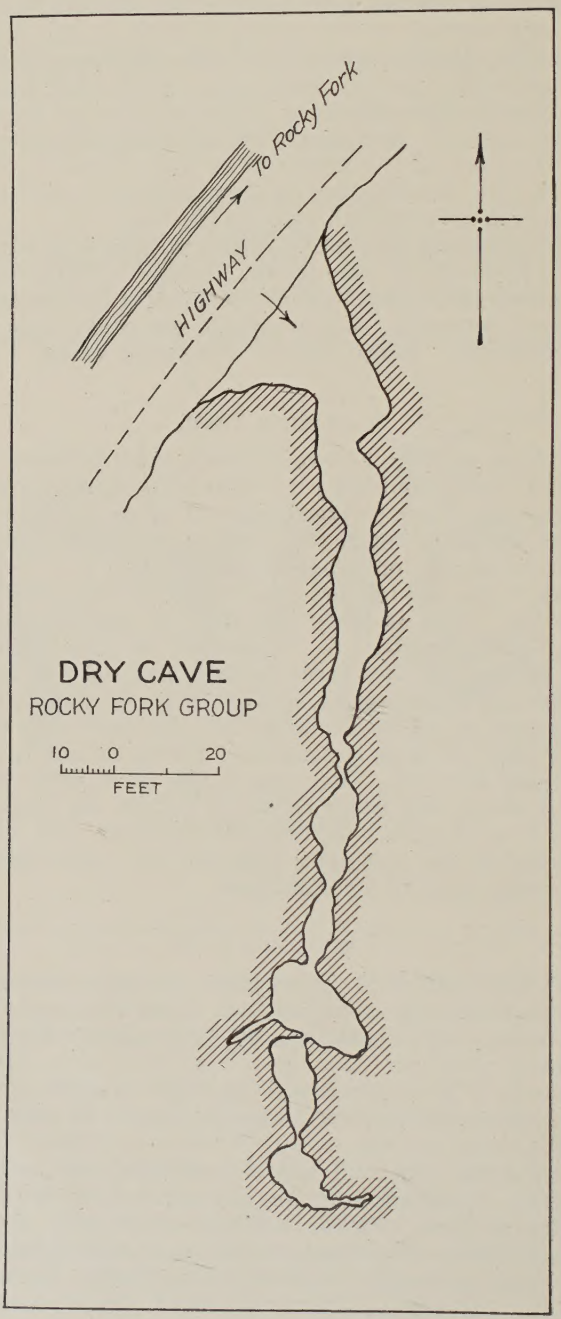
There seems to be no drainage into the cave, not even in rainy seasons. While the floor is somewhat damp, no solvent action is at work enlarging the cave. Because of the steep slope of the surface immediately above, the water runs over it into the creek, rather than into the cave, as it must have done at one time. The name has been given because of the travertine deposits, but these seem much less marble-like than those of several others.

ELLISON'S CAVE.

Ellison's Cave, which is very seldom visited, is across the gorge of Rocky Fork, almost opposite Cave Run. The entrance is from the side of a small ravine, which is really a hanging valley, tributary to that of Rocky Fork.

The opening is 20 feet wide and the length is approximately 75 feet. A passage continues in an almost straight line for 60 feet, where a right angle turn is found and the cave terminates in 12 feet. The height at the entrance is six feet, and this is maintained for at least half the distance, where it rapidly diminishes to two feet for a very short distance, and then rises to three, which it maintains to the end.

Many sink holes are present on the north side of Rocky Fork, one being, as nearly as could be determined, directly above the end of Ellison's Cave. In wet seasons water flows into it, because clay to a depth of at least two feet is present at the end of the cave, and dried


To Rocky Fork
HIGHWAY
DRY CAVE
ROCKY FORK GROUP
10 0 20
FEET

mud occurs from here to the entrance, the thickness decreasing in that direction. This indicates that in rainy seasons fine material is washed into the cave through the sink hole, a part of which is then carried toward the entrance.

The walls and roof are covered with marble-like travertine in a better state of preservation than in any of the other caves of the group. While no deposition is now going on, and the travertine has assumed a weathered appearance, it has not been smoked by candles and torches of visitors, as have the other caves. The roof and walls are irregular, owing to the varying thickness of the deposits. This cave is seldom visited because of the difficulty of access.

DRY CAVE.

Dry Cave is genetically related to the other caves of the Rocky Fork group. It is about a mile west of the main group, on the south side of the bank of a small stream which flows into Rocky Fork. The entrance, which is 30 feet above the stream level, is 10 feet high and arch-shaped. The cavern extends 180 feet south, almost in a straight line. The walls and roof are very irregular, partly due to the varying thickness of the deposits, and partly to the unequal solution of the rock walls. The cave rises very slightly, about three feet, to within a few feet from the end, where there is a vertical rise of four feet. The height varies from 6 to 10 feet in most places, but in one it is 20 feet.

As the name indicates, there is no water in Dry Cave, and there is no indication of any running into it even in rainy seasons. Because of this, no new travertine is being deposited so that the very thick covering on the walls and roof is dry and lusterless in appearance. This material is several feet thick on the roof at places, and indeed, the whole interior is so covered that except on the floor, bedrock is visible at very few places. The floor is covered with clay, packed hard by the many visitors. About two-thirds of the distance from the entrance, a mass of rock, similar in shape to a bunch of grapes, is pendant from the roof. It is five feet long and three feet in diameter, the sole support being two small columns of rock not more than eight inches in cross section.

This cave has apparently had its origin in solution along a joint, as shown by the enlargement upward at several places, and by its relatively straight course.

No data are at hand concerning the discovery of this cave. Whereas a single fee of ten cents to the grounds admits to all the other Rocky Fork caves, a charge of ten cents is made for visiting Dry Cave, which is under different ownership. No guides are necessary because the cave has no passages to confuse the visitor, parties procuring candles and walking to the end, or as far as they wish, then retracing their steps to the entrance.

Origin of the Rocky Fork Caves.—From the preceding descriptions it will be seen that the entrance to all the caves is at nearly the same elevation, and is about 50 feet above the present drainage. Thus the water falling on the surface is carried off immediately to the streams, because of the great relief, rather than soaking through the mantle rock into the caves and flowing out through them, as must have been the case before the relief was so great.

The glacial boundary is five miles east of the caves. Rocky Fork is flowing in a post glacial gorge. In preglacial time the drainage was not by the present Rocky Fork, for observations show that this stream, eight miles to the southwest, flowed southwest, rather than northwest, as it does now. The glacier in its advance dammed preglacial Rocky Fork in its southwestward course, causing it to reverse itself, and cut its present gorge about 75 feet below the general level. It lowered its bed so rapidly that the small streams, flowing mostly from caves, could not cut down as swiftly, as is attested by a hanging valley whose stream flows from the south about midway between Dry Cave and the main group. This hanging valley is about 40 feet above Rocky Fork, and is a former cave with the roof fallen in, because at the mouth of the valley several large blocks of stone are present in the stream bed, that match, and if raised in place would fit perfectly, restoring the one time arch-shaped character of the former cavern.

Doubtless the glacier, though sluggish at its greatest extension, still was able to remove a little material, and thus decreased the amount of rock between the surface of the ground and the roof of the caves, which would tend to weaken the latter. Very probably the caves along Cave Run were at one time merely branch passages from a much larger one whose position was that of the present stream. In other words, Cave Run has probably cut down through the floor of a former cavern, whose roof has collapsed.

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